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North American Sundial Society

The Compendium*

Fr. Emmanuel Maignan's catoptric dial at *Rome's* Convent of Trinità dei Monti, ca. 1637.

All the beauty of life is made up of light and shadow.

– Leo Tolstoy in 'Anna Karenina'

* **Compendium**... *"giving the sense and substance of the topic within small compass." In dialing, a compendium is a single instrument incorporating a variety of dial types and ancillary tools.*

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Robert L. Kellogg, Potomac MD

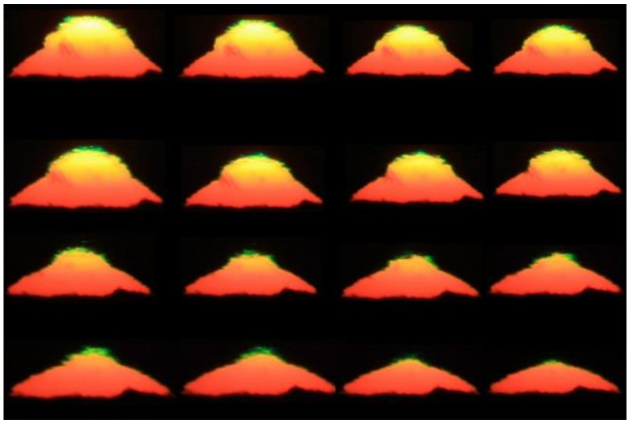

Fig. 1. Sunset Green Flash. 1978. Wikipedia.

Many years ago, when I was in the US Navy, I was stationed in the Philippines and was fortunate enough to have housing that looked over the South China Sea with a clear view of the ocean horizon. There were many evenings that I patiently watched the sunset, hoping to get a glimpse of the green flash, a phenomenon where atmospheric refraction bends green wavelengths back to earth as the last glimmer rays of the sun disappear. Fig. 1 shows the green flash submitted to Wikipedia by an excellent observer in 1978. In my two years of watching, I think I only saw it briefly once. The problem with visual observation is that as you watch the sun dip into the horizon, the red and orange glow makes the sun's after-image on the eye look green. Did I see a green flash or just the after-image? This is the same phenomenon for doctors in surgery and why the rooms and surgical gowns are usually green... it is easier on the eyes after staring at red.

Here we ask a perhaps simpler question "when does the sun rise and set?" and what does this mean for our sundial's first and last shadow?

Dialists normally use the geometrical equation to compute the solar hour angle for sunrise and sunset, when the center of the sun is on the horizon, ignoring all other effects:

$$cos(\,HA) = \frac{-\,sin(\varphi)\cdot sin(\delta)}{cos(\varphi)\cdot cos(\delta)} = -\,tan(\,\varphi)\cdot tan(\,\delta) \qquad (1)$$

where	*HA*	is the hour angle of the sun	(degrees)
	ϕ	is the latitude	(degrees)
	δ	is the declination of the sun	(degrees)

For example, here in Washington DC at latitude 39° on the summer solstice (δ = 23.45°) we find cos *HA* = −0.35126 and the hour angle *HA* = 110.56°. Because one hour is 15° of arc, dividing *HA* by 15 gives 7.371 hours or 7h 22m 16s since the sun was on the meridian. To find sunset in civil time, I need to know when the sun was on the meridian in clock time. The adjustment comes from longitude offset and the Equation of Time. I am 2° west of the 75th meridian so I need to add 2° × 4 minutes per degree, to get 8 minutes of longitude delay, in order to describe when the sun set compared to civil time. To complete the time adjustment, I need to include the Equation of Time. The British Sundial Society's table gives, for summer solstice on June 21, 2019, an additional delay of 1m 46s ("dial slow"). This allows us to do the sums for sunset as:

7h	22m	6s	hour angle from solar noon
12h	0m	0s	civil noon
	8m	0s	longitude delay of sundial to civil time
	1m	46s	Equation of Time of sundial to civil time
19h	32m	2s	civil time the center of sun is on the horizon for sunset

Of course, we really want the upper limb of the sun to vanish below the horizon to declare sunset. The sun appears to be about 32′ (arc minutes) in diameter, so geometrically we should wait for the sun to dip −0.26° below the horizon.

Equation (1) for the hour angle now becomes:

$$cos(HA) = \frac{sin(dip) - sin(\varphi)\cdot sin(\delta)}{cos(\varphi)\cdot cos(\delta)} \qquad (2)$$

where *dip* is the angle of the sun below the horizon (degrees).

Note: we shall see below that for the refracted sun at sunset, *dip* = −0.833°.

Taking the geometric dip of the sun as −0.26° we get *HA* = 110.955° (an increase of 0.39° over the central sunset). The *HA* becomes 7h 23m 49s, a little over one minute later than our first calculation.

If one wants more precision, the sun's apparent diameter changes as the earth circles the sun in an elliptical orbit. At perihelion (closest to the sun) the sun's diameter appears to be 32.53′ while at aphelion (furthest from the sun) the sun's diameter shrinks to 31.46′ as shown in Fig. 2, taken by Anthony Ayiomamitis in 2005 and explained at his website http://www.perseus.gr/Astro-Solar-Scenes-Aph-Perihelion.htm.

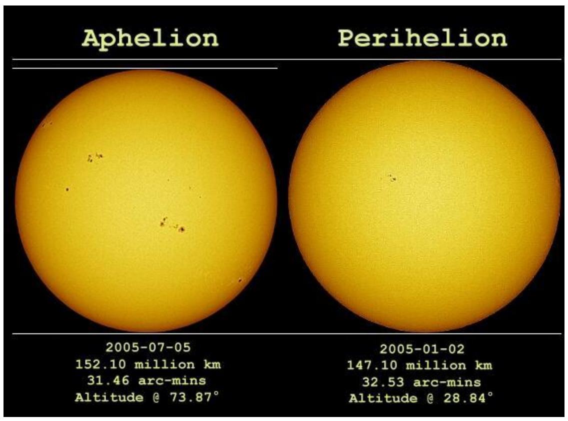

Fig. 2 Sun at perihelion and aphelion. Credit: Anthony Ayiomamitis.

But we also need to include the effects of atmospheric refraction. As we approached the 2017 eclipse, I computed [1] how many atmospheric layers we look through to see sunrise and sunset, showing that when the sun is within 5° of the horizon, sunlight travels through about 10 air masses.[1] This quickly rises to 40 air masses at the moment of sunrise or sunset, reducing the brightness of the sun by a factor of 1/28,000.

As sunlight travels through the earth's atmosphere there is considerable change to our view of the apparent sun: Rayleigh scattering (proportional to $1/\lambda^4$ where λ is the wavelength of light) efficiently scatters blue light out of the sunbeam, leaving us to view of the sun in reds and orange. The earth's atmosphere also refracts sunlight, bending the rays earthward. The difference between the refracted angle and the real angle is called deviation, δ. Néda and Volkán-Kacsó [2] computed the deviation using a realistic atmospheric model[2] and numerically traced the rays of yellow light (λ = 500 nm) for angles near the horizon.

These ray-tracing models involve the 'refractive invariant', meaning that along a refracted light path defined as *r(z, n)*, the value of *n r sin(z)* is constant and remains invariant, where *r* is the radial distance from the center of the Earth; *z* and *n* are local values of the refracted zenith angle and the index of refraction of air respectively [3].

An example of sunlight traces with exaggerated index of refraction is shown in Fig. 3.

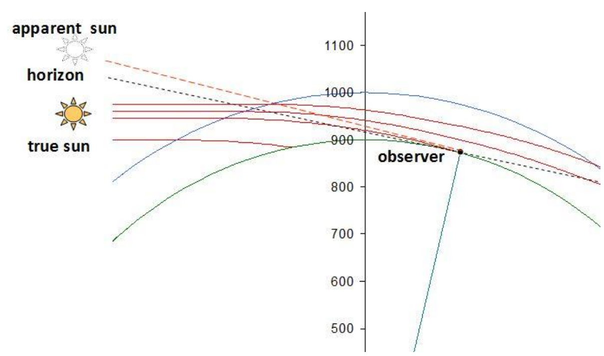

Fig. 3. Example of Ray Tracing Sunbeams. [3]

[1] An air mass is the nominal amount of air when looking through the atmosphere straight up. The majority of the earth's atmosphere is contained within about 10 km of the earth's surface, exponentially decreasing with altitude.

[2] On method of modeling the density of the atmosphere is to use a "polytropic" set of indices of refraction, *n(height)* for dominant layers of the atmosphere: troposphere, tropopause, stratosphere and mesosphere. rising through each layer the atmospheric density is determined by an exponential decay using a layer scale height. Each of the layers must be continuous in density across layer boundaries. These calculations are not for the faint of heart.

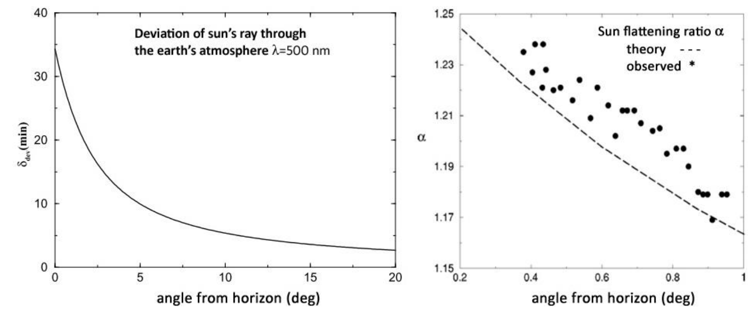

Fig. 4. Atmospheric Deviation and Sun Flattening Ratio. From Néda and Volkán-Kacsó.

Fig. 5. Photo of Setting Sun. The Boon Companion 2016.

Néda and Volkán-Kacsó used their results to determine the deviation of the upper and lower limbs of the sun and find the sun's flatness ratio. Then they compared the numerical calculations with observations made in South Bend, Indiana as shown in Fig. 4. The agreement is close but systematically biased. You can do your own flattening measurement using a photo of the setting sun in Fig. 5.

NOAA's Sunrise/Sunset and Solar Position Calculators incorporate a variety of equations to represent atmospheric deviation, based on average temperature (T), sea level pressure (P) and humidity (H) conditions (see https://www.esrl.noaa.gov/gmd/grad/solcalc/calcdetails.html; Jean Meeus' book *Astronomical Algorithms* provides more details, as well as alternative equations). For standard values of T, P, and H at the ocean (height = 0) the commonly accepted *dip* angle for sunrise and sunset is −0.833°. Using Eqn. 2 from above, *HA* = 111.818° or 7h 27m 16s. This is *five* minutes longer than the geometric sundial's sunset at *HA* = 7h 22m 16s. As one travels north or south from the equator this deviation becomes greater and greater (and of course near 66° latitude one can get sunset for 24 hours).

As mentioned, the extent of the refraction depends surface air temperature and atmospheric pressure. When the weather changes to a high-pressure system with lower than average temperature, the larger the refraction angle. So, if you watch the sun set in an area of high pressure on a cold day, you may have to wait several seconds longer than the standard prediction for the sun's upper edge to finally disappear behind the horizon.

These sunrise and sunset computations are normally done for sea level. But what happens if you are in Denver? In truth your sunset will be blocked by the Rocky Mountains. Observations with a sea level horizon at a high elevation (such as an aircraft) require additional corrections resulting in:

$$dip = -0.833° - \frac{1.15°}{60}\sqrt{elevation} \qquad \textit{elevation} \text{ is in meters above sea level} \qquad (3).$$

Suppose that we are flying over Washington DC at 5,000 meters. The corrected *dip* angle is now -2.188° and sunset on the solstice now occurs with *HA* = 113.880° or 7h 34m 31s. That is 12m 15s after our ground-based sundial and 7m 15s after a ground-based observer sees the last edge of the sun set. We hardly ever would consider measuring sunset from an aircraft, but I do radio propagation studies with the ionosphere 320 km above the earth. Sunrise, sunset, and time of year that the ionosphere is in continual sunlight or darkness differs dramatically from observers on the ground.

Bob Kellogg *rkellogg@comcast.net*

References

1. Kellogg, R.L., Sundial for Starters, *The Compendium*, 23(1), pp 1 - 4, March 2016.
2. Néda, Z. and Volkán-Kaskó, S., Flatness of the Setting Sun, *American Journal of Physics*, 71(4), pp 379 - 385, April 2003. http://adatbank.transindex.ro/vendeg/htmlk/pdf5001.pdf.
3. Casselman, W. Atmospheric Refraction and Related Phenomena [undated Powerpoint slides]. http://www.math.ubc.ca/~cass/courses/m309-04a/atmospheric3.pdf.

The Van Vleck Observatory Sundial – My Design Process

Robert Adzema, Palisades, NY

It started over twenty years ago when Wesleyan University's Astronomy Department contacted me about making a sundial for them. After a number of sketches a design was selected, but the university realized it did not have the budget for the substantial dial they wanted.

Last winter, with a larger budget in hand, Wesleyan again contacted me to see if I was still interested in making a sundial for them.

Fig. 1. The Van Vleck Observatory (before sundial).

Without hesitating I revisited the Wesleyan Campus in Connecticut and the Van Vleck Observatory. They were looking for a dial to be placed close to the building. Almost immediately I saw a spot on the curved sandstone wall between the two windows on the south side of the observatory. The building is on the highest spot on the campus. The wall receives full sun most of the day all year long. It was a perfect location for a sundial. For viewing, it offered an open, level, comfortable area (Fig. 1.)

The building, which was built in 1916, was designed so that its major axis faces directly east-west. The space between the two windows on the south side of the curved wall of the building's dome therefore faced directly south and was ideal for a direct south, vertical dial. It was also up high enough to be out of reach of any mischievous students.

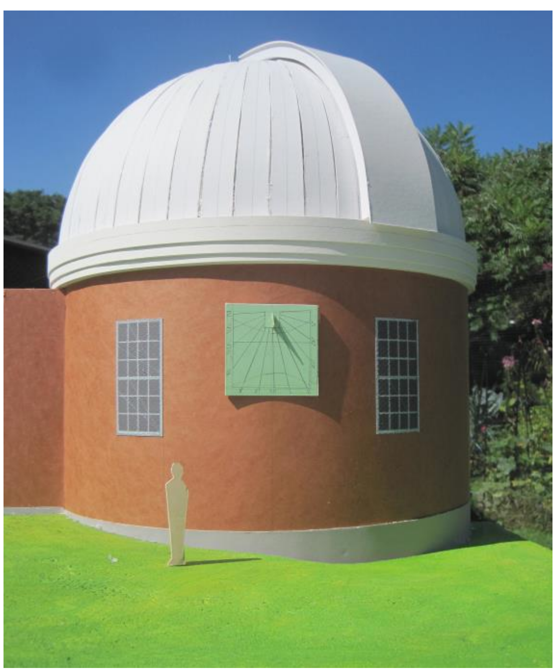

Fig. 2. Sundial maquette – scale: ½" to 1' 0".

Early on, my vision was for a flat dial plate that would be a nice visual contrast to the curved wall. It would also be less complicated to design. They agreed with my choice of this location and a vertical dial.

William Herbst, the senior astronomer at Wesleyan, was my principal guide along with his colleagues, in determining the functions that the sundial would provide. He wanted a dial that was not too complicated and that would serve as an educational tool for the students. We settled on a flat dial plate telling the hours, the equinox and the summer and winter solstices. It would tell standard time and I would build in a longitudinal correction. A plaque on the wall below the dial would provide the equation of time correction to get standard time. The program was straightforward and clear. The dial would be simple, yet classical and look like it was part of the building.

A major task in any of my public sundial projects is fit. The sundial must be large enough to compliment the building or landscape yet not so large as to dwarf the human scale or connection. The form, color, materials, and content of my sundials must also be harmonious with their surroundings.

Using a ½″ to 1′ 0″ [1:24] colored, scale model (Fig. 2), I was able to test the size and proportions of various designs. Would it be rectangular, vertical or square?

I have always found using a scale model of a site is a great design tool to quickly test numerous design ideas and to give the client a realistic idea of my vision. It is a much better tool than communicating and designing with two-dimensional images.

We agreed on a design for a 6′ × 6′ square vertical south dial.

I researched other vertical south dials on the web and kept coming back to the Queens' College dial in Cambridge, England. It is a beautiful dial, but has too many functions and layers for easy reading. What I found striking and used was the layout of the border and the Roman hour numbers that take their shape from their corresponding hour angles.

What should the dial be made of and how can I integrate it with the historic red sandstone wall of the observatory? Would it be a monolithic stone, cast concrete or fabricated in metal? What material would be cost effective and least disturb the historic stonework of the observatory?

When a weathered bronze mailbox with a beautiful green patina in the old door of the Observatory caught my eye, I suggested we make the sundial in bronze and give it a similar patina. It would also be a complimentary color to the rust colored sandstone.

My next step was to accurately lay out the geometry of the dial hours and seasonal lines. I like to compute them three ways:

1. Graphically on my drafting table.
2. Mathematically using trigonometric formulas.
3. Using Francois Blateyron's *Shadow-Expert* computer program.

In addition, I consulted Fred Sawyer, President of the North American Sundial Society, for his input and to check my numbers with his sundial computer program.

One issue that arose in the layout was that the ends of the curved line of the winter solstice generated by the nodus point of the gnomon terminated at the horizon line. At this point the solstice line would continue horizontally straight outward east and west toward the edges of the dial. Professor Herbst was strong in his opinion to end the solstice line at this transition - his point being that students, hopefully, might ask "Why?"

Satisfied with my layout, I made a full size, colored, wood prototype (Fig. 3).

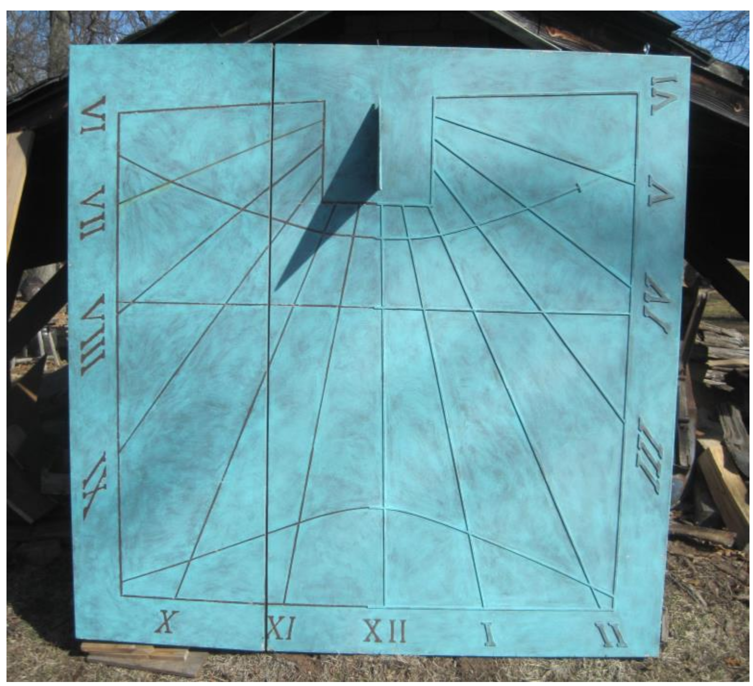

Fig. 3. Full size wood mockup.

Would the sundial lines be raised or etched? I decided that the raised lines would be more visible from a distance. I was now able to see how all the raised line thicknesses, their shadows, the size of the hour numbers, and solstice and equinox lettering looked outside in the sunlight.

Satisfied, I took it to the site and positioned it on the wall to see for myself if the scale and color were right and to get confirmation from the university that they concurred with my sizing and design (Fig. 4).

With their acceptance, I proceeded to produce a set of production scale drawing hand-drawn on my drafting table, that I would give to my fabricator (Fig. 5).

Fig. 4. Field testing the mockup on the building.

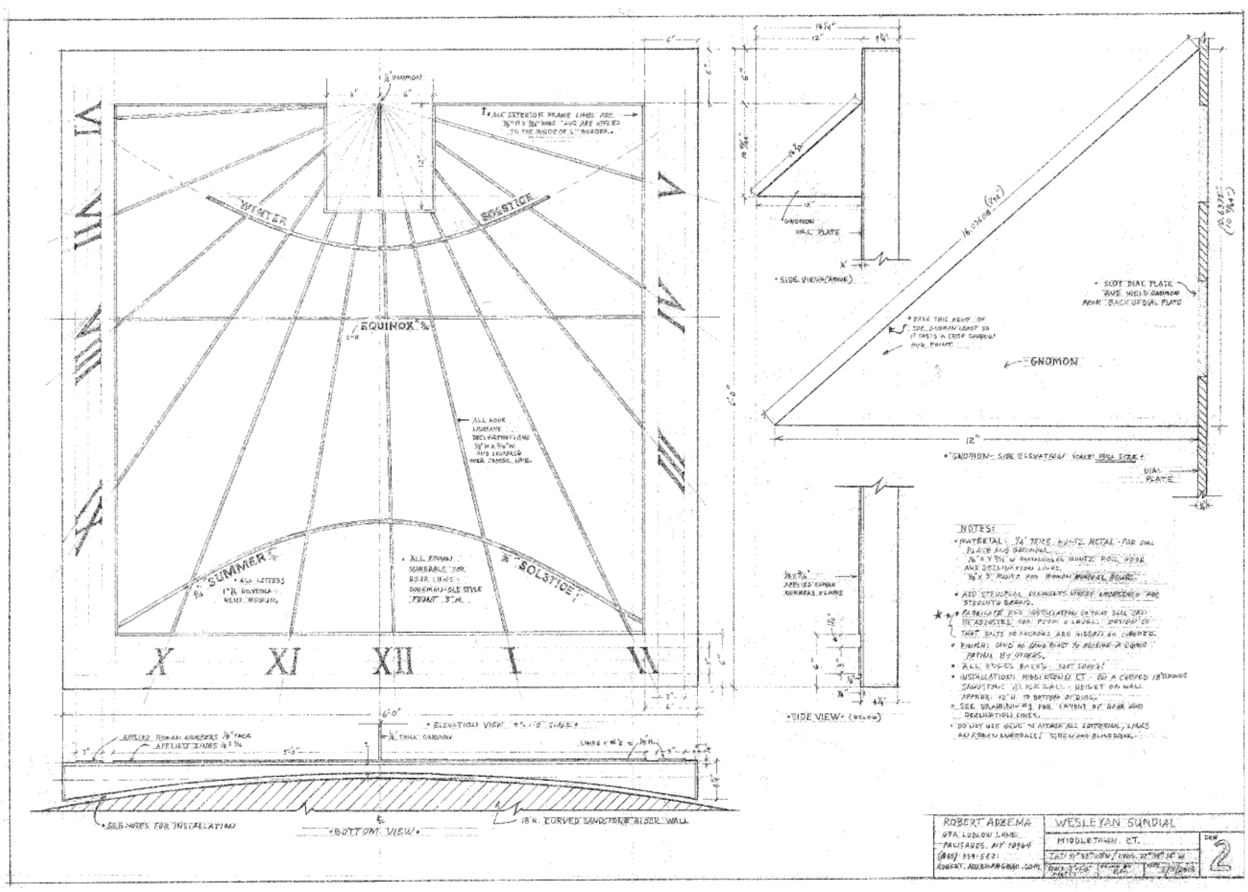

Fig. 5. A production drawing sheet #2.

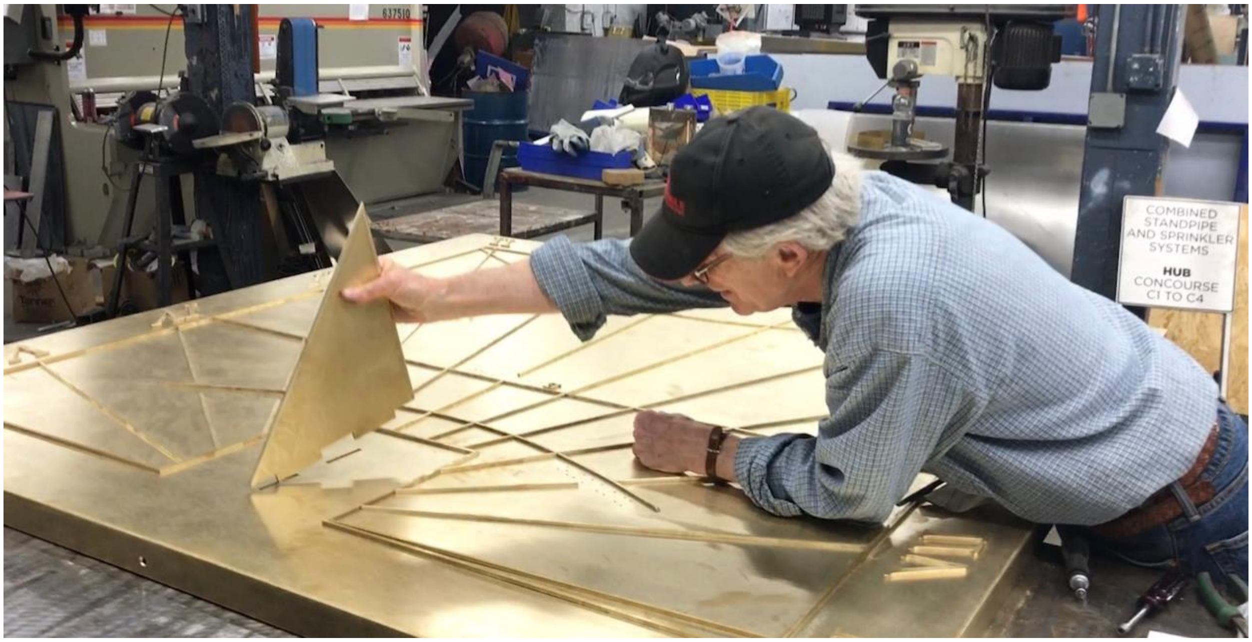

Fig. 6. Fitting the bronze gnomon into dial plate.

One challenge was to work out a hanging system on the back of the dial that would have minimum impact on the stonework. It would also have to permit the final adjusting of the dial to tell the accurate time from all four corners on a rough, very uneven, curved sandstone wall and be strong enough to hold the dial's weight of about 700 lbs. (Fig. 6).

The final and most sensitive stage of the sundial's finishing was the hot application of the patina. Applying a combination of acids on bronze with heat produces a durable and beautiful patina (Fig. 7). The heating of the bronze caused the large flat bronze plates to warp. Although I had suggested to the fabricators that a stainless-steel frame and enough structure behind the large flat area which was to be heated was necessary, I let the fabricator determine the structure. Unfortunately, I had to add additional structure to the back of the sundial to re-flatten the face without disturbing the beautiful patina we had achieved. It was the most challenging part of the project and I would investigate applying the patina cold in the future, or make sure that my fabricator supplied adequate structural detailing.

Fig. 7. Applying the patina.

To install the sundial, we used an all-terrain scissor lift to lift and maneuver the dial into position (see Figs. 8 - 10).

The university, the astronomy professors, students, and myself were thrilled with the results. Any error in function due to the warping has been mostly eliminated to a small margin of error. The Van Vleck Observatory Sundial at Wesleyan University is doing its job telling time and the seasons from the sun, as a great teaching tool for the astronomy students, but also as a beautiful object for their historic observatory and for the Wesleyan University Campus (see Figs. 11, 12, following pages).

Fig. 8. Loading the dial onto the scissor lift.

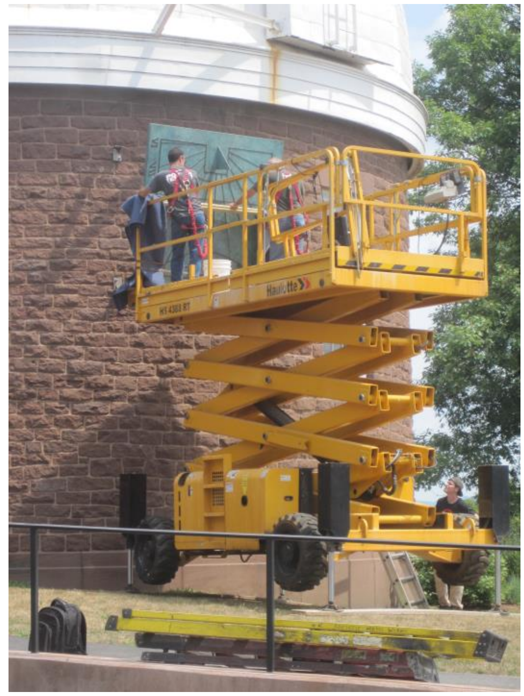

Fig. 9. Positioning the dial on the curved wall.

Fig. 10. Plumbing and leveling the dial.

Fig. 11. Wesleyan University's Van Vleck Observatory Sundial, installed July, 16, 2018.

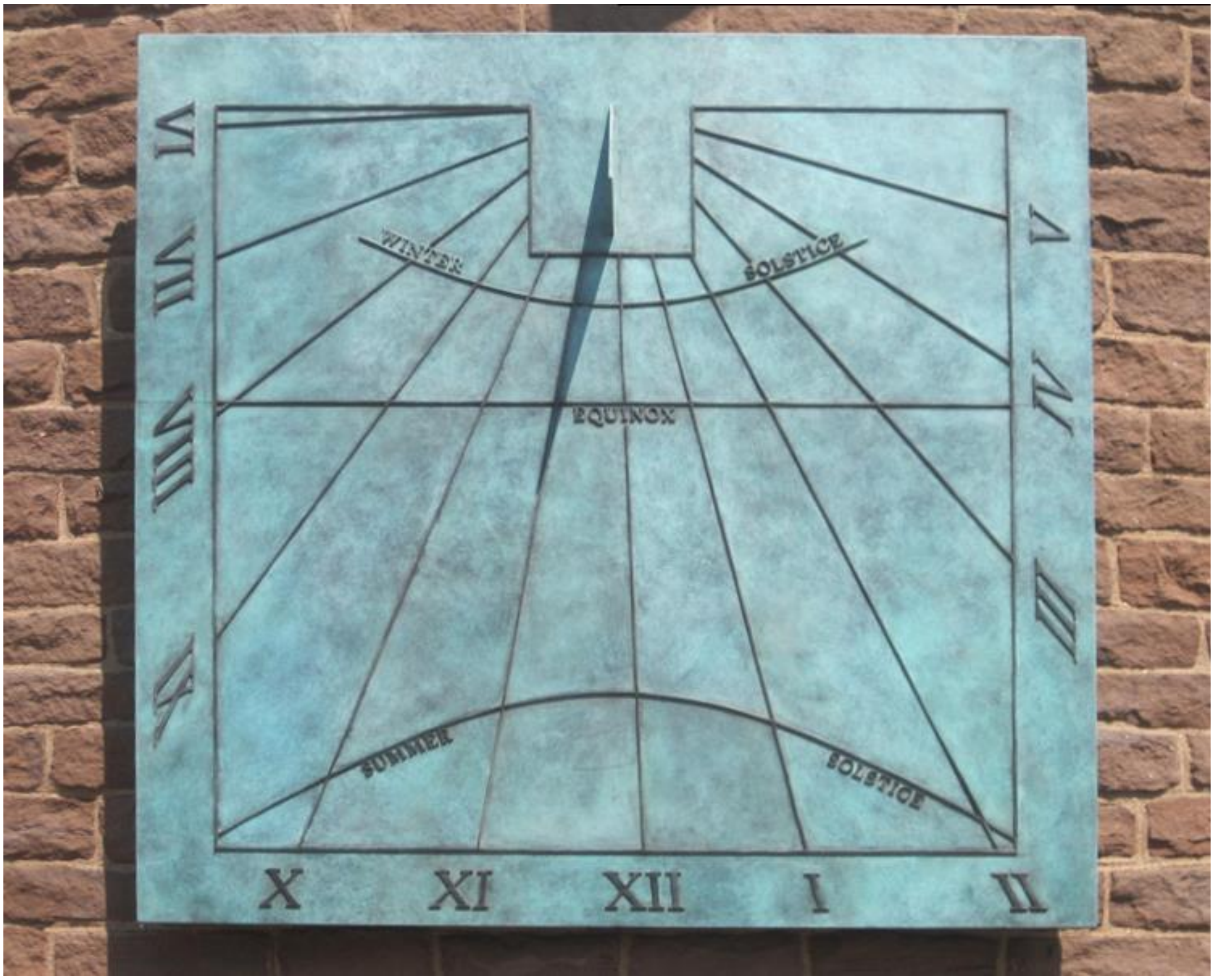

Fig. 12. The Van Vleck Observatory Sundial.

Location:	Wesleyan University, Middletown, CT. 4l° 33′ 20″ N, 72° 39′ 34″ W.
Type:	Vertical Direct South Sundial.
Material:	Bronze.
Size:	6′ 0″× 6′ 0″.
Design:	Copyright Robert Adzema, 2018.

If I have succeeded as a sundial artist, it is my hope that my dials will invite someone to pause in their day, to notice the simple beauty of sunlight and shadow and to feel connected to their surroundings at that very moment in time.

~ Robert Adzema, 2019

Robert Adzema *robert.adzema@gmail.com*

[See also https://newsletter.blogs.wesleyan.edu/2018/07/17/sundial-sculpture-installed-on-van-vleck-observatory/. Other examples of Robert Adzema’s sundials can be seen on his website: http://www.robertadzema.com.]

Tres Riches Heures

Mark Montgomery, Chesterton, IN

The Duc de Berry's *Tres Riches Heures* ("Very Rich Hours") is a famous prayer book for the Catholic layman of the Middle Ages and art connoisseurs of today. Commissioned in 1412, each calendar page shows rich details of early 15th century life, Fig. 1. Atop the picture for each is a series of semi-circular arcs containing numbers, symbols, and star patterns. This article will review a brief history of medieval canonical hours; the calendar contained in the *Tres Riches Heures*; and the function of each mysterious arc.

Canonical Hours (2, 3, 4)

The custom of praying at fixed times during the day is an ancient tradition. In Psalms 119:164, King David writes, "Seven times a day I praise you for your righteous laws." However, Jewish prayer usually consisted of morning, afternoon, and evening prayer (Daniel 6:10). Most likely, the Apostles continued this practice as the early Christian church was established (Acts 4:24). The time of prayers were:

1. Matins: 9th - 10th hour of night upon awakening, (Psalm 1:2).
2. Lauds: Dawn, (Psalm 55:17).
3. Terce: 3rd Hour, (Acts 2:15).
4. Sext: 6th Hour, (Mark 15:33, Acts 10:3, 10:9).
5. None: 9th Hour, (Mark 15:33, Acts 3:1).
6. Vespers: Evening lighting of lamps, (Psalm 55:17).
7. Compline: Night prayer before retiring, (Psalm 1:2).

The hour Prime, 1st hour, was added to the original seven hours by St. Benedict during the 6th century.

During daylight hours, monks used mass dials to determine the time to start prayers. Mass dials were seasonal (unequal) hour sundials with Terce, Sext, and None usually marked by extra thick hour lines or crosses on the prayer hours. Fig. 2 shows a mass (scratch) dial.

T. W. Cole states churches were whitewashed at regular intervals. The scratches allowed the hour lines of the dials to be repainted without having to layout new hour lines (5).

Fig. 1. June (1)

Development of Books of Hours (7, 8, 9, 10, 11)

Prayers originally focused on the Psalms, or a Psalter. A brief, anonymous book known as *The Didache*, The Teachings of the Twelve Apostles, was written in the 1st century AD and is the first known Church Order. It recommended including the Lord's Prayer whenever worshiping. Prayers continued to evolve as the early Church Fathers further defined Church Orders, specifying prayers and prayer times.

Fig. 2. Mass dial at St Andrew's, Bishopstone, UK (6)

In the 6th century, St. Benedict founded an order of monks. They established singing prayers eight times a day. These fixed-hour prayers were called *The Divine Office*, where office is Latin for duty. St. Benedict called prayer the work of God, or *Opus Dei*. The Divine Office continued to evolve and grow into a collection of psalms, prayers, hymns, antiphons, and readings that changed with the liturgical seasons known as *The Breviary*.

In the early 13th century, the Dominican order was founded. They developed a greatly simplified set of devotions for use by lay people known as *The Little Office of Our Lady*. Since the book called for prayers multiple times during the day, it was commonly called *Les Heures* (or Book of Hours). The prayer book contained extracts from the four gospels, devotional prayers to the Virgin Mary and other saints, prayers for specific church holidays, Psalms, and litanies. Thousands of these books were made between 1250 and 1700, many of which still survive. Over time, the books became elaborately decorated.

To keep track of saint's days and other feasts, most of the books of hours begin with a calendar. One page for each month listed all of the holy days. The most important feast days were marked in red; hence they were called red letter days.

Duc de Berry's Book of Hours (8, 9, 10, 11)

The Duc de Berry, a French prince, commissioned the Limbourg brothers, Pol, Jean and Herman, to illuminate a Book of Hours. The three brothers worked on developing this extraordinary manuscript until 1416 when the plague killed their sponsor and all three brothers. Acquired by the Duke of Savoy, work started again in the 1440s by an anonymous painter, and completed in 1485-1489 by painter Jean Colombeon. In 1855, the Duc d'Aumale, one of France's foremost connoisseurs, purchased the Tres Riches Heures from a boarding school for young ladies in Genoa. Today, the manuscript is located in the Musee Conde, Chantilly, France.

The Tres Riches Heures contains 206 vellum pages, 290 × 210 mm, or 11.4″ × 8.3″. It contains 66 large miniatures and 65 small ones. The calendar is in the very beginning of the book. Each month is contained in two pages, the left-hand side is the miniature while the right-hand side lists the notable feast days. Each month contains a miniature picture in the Flemish style depicting the season's labors during the middle ages. The castles in the background were owned by Duc de Berry.

Calendar Function (8, 13, 14)

Above the monthly miniature is a series of semicircular arcs with signs and symbols which are details of the calendar for the corresponding month. Seven months are complete; October is partially completed. Fig. 3 shows the calendar detail for the month of February. The semicircles are labeled A - H, starting from the center.

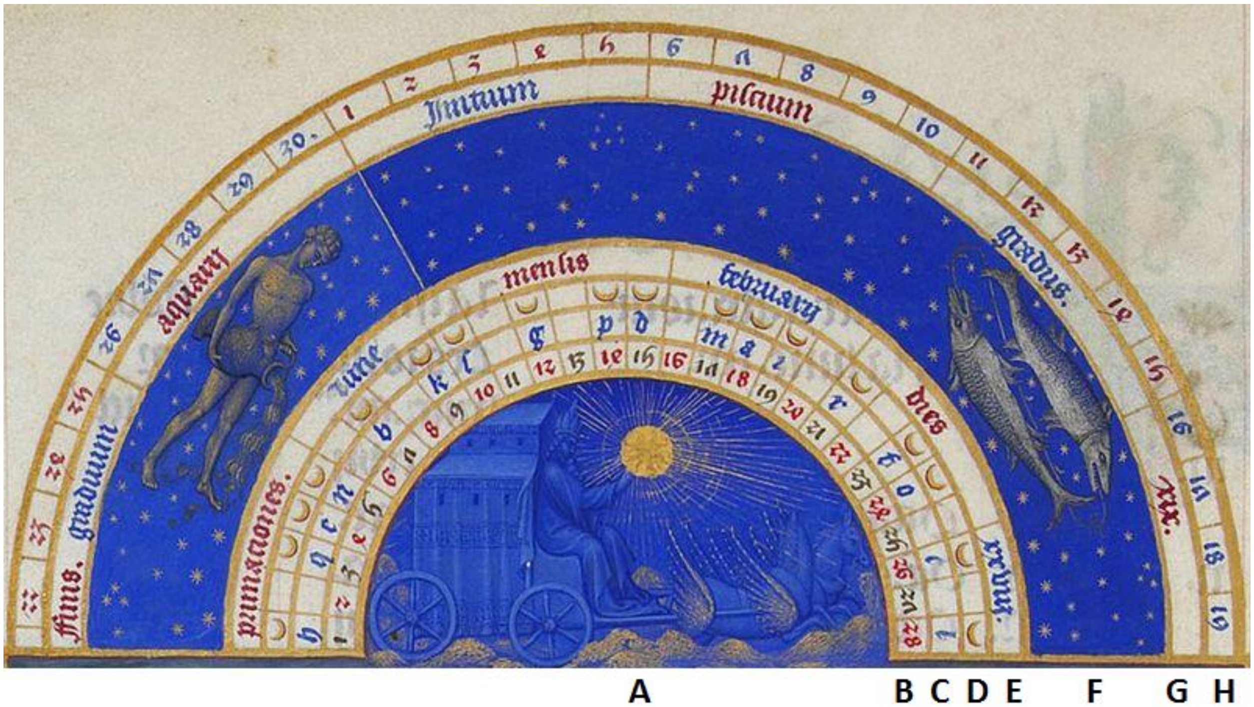

Fig. 3. Detail of Calendar Semicircle for February (12)

The innermost semicircle (A) is a painting of Apollo, the sun god, riding his chariot across the sky. Surrounding this drawing are three arcs (B, C, D) divided into 30 or 31 (or 28 for February) equal parts, one for each day of the month.

Arc B numbers the days of the month. Note how the numbers 4, 5, and 7 appear strange. They are archaic versions of the Hindu-Arabic numbers that arrived in Europe during the 12th century.

The next arc, C, is a lunar almanac for the month and contains information on the 19-year Metonic Cycle. During the middle ages in Europe, each year was given a *Golden Numb*er that identified its place in the Metonic Cycle. The number was used to determine the date for Easter, which was painted gold in the manuscript. The first documentation of the term Golden Number was in a poem *Massa Compoti* by Alexander de Villa Dei in 1200. To find the Golden Number of any Julian or Gregorian year, divide the year by 19. The golden number is the remainder plus 1 (e.g. 2018 ÷ 19 = 106, remainder 4; the golden number for 2018 is 4 + 1 = 5). At this time, the date for Easter was computed; not based on astronomical observation. The Golden Number was expressed similar to the Milesian Greek system, using alphabet letters as numbers (a = 1, b = 2, c = 3, etc.). Thus, the first 19 letters of the alphabet show the calendar date of the new moon. Note, the letter *j* was adopted into the alphabet in the late 15th century and is missing from this tabulation. A close look at the letters will show a Gothic script called *Bastarda*, a mix of two or more French scripts, created during the 15th century in Burgundy.

The third arc, D, contains a crescent moon drawn on the days marked by a Golden Number in arc C.

Arc E contains a Latin inscription describing the information in the prior two arcs and the number of days in the month. In Fig. 3, the February inscription reads “Primationes lune mensis February dies xxviii” or “The new moons of February, 28 days”.

The next large semicircle shows the symbols of zodiac constellations for the month in which the sun can be found. The end of one sign and beginning of the next is clearly marked by a radial line at the appropriate part of the month. For February in Fig. 3, a line is drawn from the 10th day, which is when the sun leaves Aquarius and enters Pisces.

The next two arcs describe the sun’s location in the zodiac. The twelve signs of the zodiac each occupy one-twelfth (30°) of the sky. Thus, arc H divides each zodiac constellation into 30 equal parts which aligns so that the sun’s position is shown for each day of the month.

The remaining arc, G, contains a Latin description of arcs F and H. For instance, in February we find written over the first 10 days of that month “Finis graduum Aquary” or “The last degree of Aquarius”, and over the remainder of the month “Initium Piscum gradus xix” or “The beginning of Pisces, 19 degrees”.

Thus, by knowing the meaning behind the mysterious arcs atop the monthly miniature pictures, we can more fully appreciate these great works of art.

Why did Books of Hours disappear from use? A new devotional practice was developed during the 15th century that was simpler to use and did not require literacy. *The Rosary* gradually displaced the Book of Hours as the way of saying Christian prayers in a prescribed sequence.

Mark Montgomery *mark.montgomery2003@yahoo.com*

References:

1. By Limbourg brothers - R.M.N. / R.-G. Ojéda. Public Domain. https://commons.wikimedia.org/w/index.php?curid=108569
2. “Concordia Self-Study Bible,” Concordia Publishing House, St Louis, 1984.
3. Canonical Hours – Wikipedia. https://en.wikipedia.org/wiki/Canonical_hours
4. Tierney, Brian, “Western Europe in the Middle Ages: 300 - 1475,” 6th ed., McGraw Hill, Boston, 1983. pp 56-59, 359-367.
5. Cole, T. W., “Origin and Use of Church Scratch-Dials,” Hill Bookshop, Wimbledon, 1935, pp 1-9.
6. Bishopstone East Sussex – Wikipedia. https://en.wikipedia.org/wiki/Bishopstone,_East_Sussex [Image by ‘Poliphilo’ used under Creative Commons Licence]
7. A Hypertext Book of Hours. http://medievalist.net/hourstxt/home.htm
8. Richards, E.G., “Mapping Time, The Calendar and Its History,” Oxford University Press, 1998, pp. 379-383.
9. Stein, Wendy A., The Book of Hours: A Medieval Bestseller, Department of Medieval Art and The Cloisters, Metropolitan Museum of Art, June, 2017. https://www.metmuseum.org/toah/hd/hour/hd_hour.htm
10. Les Enluminures, Book of Hours Tutorial, http://www.medievalbooksofhours.com/learn
11. Tres Riches Heures du Duc de Berry - wikipedia. https://en.wikipedia.org/wiki/Tr%C3%A8s_Riches_Heures_du_Duc_de_Berry
12. By Limbourg brothers - R.M.N. / R.-G. Ojéda, Public Domain. https://commons.wikimedia.org/w/index.php?curid=108562
13. Golden Number (time), Wikipedia. https://en.wikipedia.org/wiki/Golden_number_(time)
14. Blackletter, Wikipedia. https://en.wikipedia.org/wiki/Blackletter

An Hours to Sunset, Solar Declining dial using a mirror in a box

Steve Lelievre (Vancouver BC)

Introduction

This article is about the dial shown in Fig. 1. It is a vertical frame with the dial face drawn on a sheet of vellum[3] at the front and a mirror in the back. A ray of light entering a small hole in the vellum is reflected by the mirror onto the reverse side of the vellum. Because the vellum is translucent, the position of the reflected spot is easily seen amid the dial face drawn on the vellum.

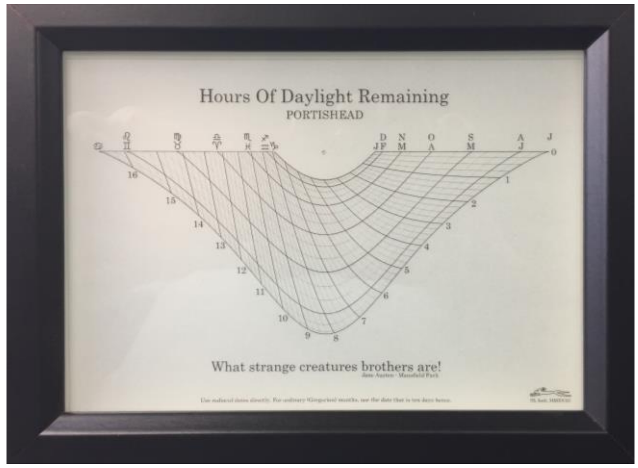

Fig. 1. Completed dial.

For use, the dial is turned until the reflected spot touches the day's declination line. The time can then be read using the transverse hour lines, as shown in Fig. 2.

The dial used to illustrate this article was a gift for my brother; hence it is laid out for his home in Portishead, UK. Instead of time of day, it shows reversed Italian hours, which correspond to the amount of time remaining to sunset.

The dial is inexpensive and easily constructed. An online program for drawing the mesh of lines is available. The program will generate both mirrored and mirrorless solar decliners; at the time of writing, the only option offered is for an Hours to Sunset dial. Point your browser at http://www.gnomoni.ca/sunsetSolarDecliner/.

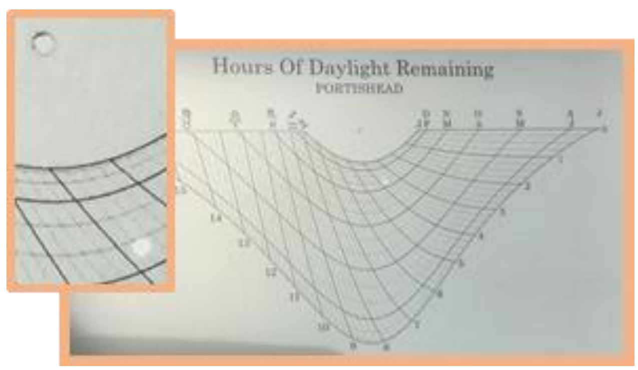

Fig. 2. Detail of the dial. The inset provides an enlarged view showing the nodus hole, upper left, and reflected spot, lower right.

Some background

Hours to Sunset dials

I was introduced to the concept of Hours to Sunset dials through reading about one made by Mac Oglesby for a Vermont airfield (Oglesby, 1997). They have been a personal favorite ever since: an interesting alternative to conventional hours, and well-suited to places where outdoor activities are usually curtailed by the arrival of dusk, such as community gardens, beaches, and parks[4].

These dials, of course, are nothing more than dials laid out for Italian hours but with changed numbering. In the Hours to Sunset system, the instant of sunset corresponds to 0, one hour *before* that moment has an hour value of 1, and so on.

3 For the purposes of this article, vellum refers to a paper-like material made from translucent polymer sheets.

4 For example, I prepared the design for an Hours to Sunset dial for the Mactaquac Provincial Park in New Brunswick, Canada. In addition to the hour lines, the dial had a colored line for each of the park's designated walking trails, positioned according to expected walking time so that users would know not to start out on a trail too close to sunset. Disappointingly for me, the project was never completed.

For conversion from an Hour Angle ω to Italian Hour t_i we can use

$$t_i = \left(24 + \frac{\omega - \omega_{ss}}{15}\right) mod\ 24 \qquad [1]$$

$$\cos \omega_{ss} = \tan \varphi \tan \delta \qquad [2]$$

where φ is latitude, δ is solar declination, and ω_{ss} is the Hour Angle of sunset. Converting t_i to an Hours to Sunset value simply involves subtracting t_i from 24 (BSS, n.d.).

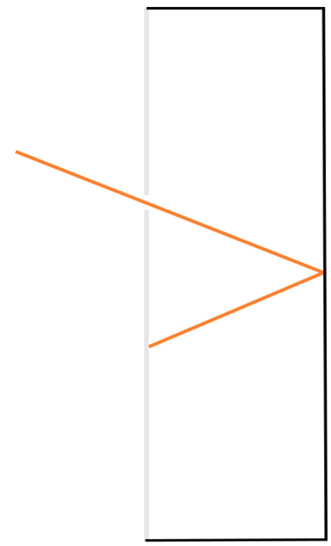

Fig. 3. Cross-sectional vertical representation of a frame and mirror sundial adapted from Kaufman's design.

Mirror in Frame Sundials

This is a type of dial suggested to me by Art Kaufman. His paper about their method of construction appears in *The Compendium*, v. 22, no.1 (Kaufman, 2015). The dials are boxes with a vellum sheet at the front and a mirror at the back. Light enters through a small hole in the vellum, travels to the mirror, and is reflected forward onto the dial face (see Fig. 3).

A special advantage of the arrangement is that the nodus, which in this design is the small hole, is part of the sheet of material used as the dial face. Consequently, most potential alignment issues are eliminated. It is simply a matter of ensuring that the vellum and mirror are parallel, at the correct distance, and square to each other.

Another advantage is that a simple box frame would be easy to construct, although in practice I purchase deep-set photo frames instead of making my own boxes.

Fig. 4. Dial components. The transparent items, polycarbonate and glass, hardly visible in this photograph, are in the middle left and lower left.

The dial is used vertically so mounting hardware is not needed, but a bull's eye level is helpful for ensuring the device is properly upright for use.

Fig. 4 shows, clockwise from bottom left, the parts involved:

- clear polycarbonate front sheet [G],
- vellum sheet with dial diagram,
- clear glass sheet,
- spacer [G],
- outer frame [G],
- fiberboard back cover [G],
- mirror.

The frame shown in Fig. 4 is larger than needed for a windowsill dial – in many situations, a frame for a 5″ × 7″ print gives excellent results with a 1/16″ nodus hole. Latitude dictates the aspect ratio of the dial face. The depth of the spacer is also relevant.

[G] If you buy a frame, make sure it is one with a clear front cover, spacer and back panel. For example, the parts marked G are from a GUNNABO picture frame purchased from IKEA. I found that this product line is made well enough to provide the precise spacing and alignment needed. However, in some cases I have to glue some small paper squares to the bottom to act as permanent wedges (after establishing the perfect vertical of the assembled dial face using a trusted horizontal surface as a reference). The mirror and glass pane are separate purchases.

Comparison to catoptric sundials

Catoptric dials[5], often referred to as mirror dials or reflection dials, use light reflected from a small mirror.

The convent of Trinità dei Monti, Rome, hosts the spectacular example shown in Fig. 5. A small mirror placed on a window sill creates a bright spot on the vaulted ceiling of the adjacent corridor. Assorted hour lines and astronomical indicators crisscross the ceiling.

A more recent example, described in a recent issue of the BSS Bulletin, is the stylish outdoor dial recently installed by Graham Parks at his home near Salisbury, England (Parks, 2018). This one has a vertical south-facing mirror mounted on a metal support extending from a north-facing wall, so that a bright spot can be reflected back onto a dial face mounted on the wall.

It must be noted, however, that there is a fundamental gnomonic difference between these dials and Kaufman-type dials[6]: for a catoptric dial, the nodus is the little mirror, whereas for the Kaufman, the nodus is the little hole in the vellum. The Kaufman mirror only relates to the physical construction – the front to back dimension of the frame is halved, and, as mentioned above, alignment of the parts is simplified. For this reason, I suggest we should not describe the Kaufman dial as a catoptric dial (nor use alternative names: mirror dial, reflection dial etc.)

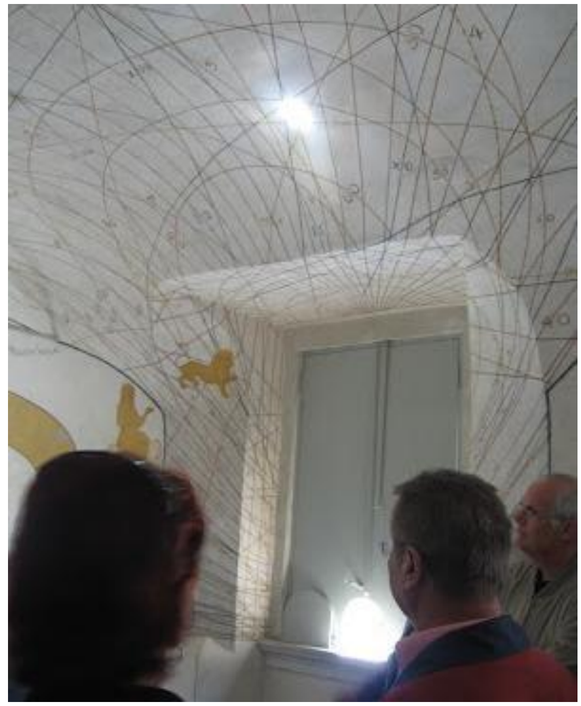

Fig. 5. Catoptric dial at the Convent of Trinità dei Monti. The dial dates from circa 1637 and is attributed to Fr. Emmanuel Maignan, a French theologian who was the convent's professor of mathematics for 16 years.

Photo courtesy of Siân Bonnell.

Solar Decliner Sundials

Generally, over much of the year, Vertical Dials function for only part of the day: they accept sunlight over less than 180° of azimuth. Even with the sun in front of the dial, there are periods when the nodus' shadow is left or right of the dial face, and for part of a summer day the sun is behind the dial.

For the typical setting of a wall-mounted south-facing Vertical Dial, this difficulty can often be circumvented by placing other dials on the east and west sides of the building. For portable dials, the issue is usually irrelevant: most are altitude dials that are either turned directly towards the sun, such as Shepherd's Dials, or turned fully edgewise to the sun, such as Capuchin Dials.

Another portable option is to use a Solar Decliner dial. I like to think of these as a sort of hybrid of Vertical Decliners and Shepherd's Dials. Like the former, they may have a flat (planar) dial face; like the latter, they have to be turned as the day progresses. They are Solar Decliners because they are declined relative to the sun rather than relative to a bearing.

However, unlike a Shepherd's Dial, a Solar Decliner is not turned fully towards the sun; instead, it is turned only until the shadow of the nodus touches the day's declination line. One of the best-known examples is the Roman-era Ham of Portici, 1st century CE. [see the article that follows this one].

[5] Catoptrics relates to the use or study of mirrors and reflections; ultimately from the Greek word κάτοπτρον meaning a mirror.

[6] I refer to them as Kaufman dials because I am not aware of any such dials predating his 2015 paper. Please contact me if you know of antecedents.

I am not sure when I first became aware of Solar Decliners, but I admit to not having a full appreciation of them until I attended a presentation by Fred Sawyer at the 2017 NASS conference, which provided an excellent overview of their history and principles (Sawyer, 2017). I came to understand not only the diversity and cleverness of this class of dials, but also that it is possible to construct one that covers the full span of daylight from sunrise to sunset using a flat surface for the dial face – ideal for my project.

Calculations

The calculations outlined in this section are for the simplest case. Depending on the specific arrangement used, there may be small changes in path length due to the ray passing through a pane of glass at the front of the frame, and through the glass of a back-silvered mirror. The program mentioned above makes the applicable adjustments. Subscribers to the digital version of *The Compendium* will receive a Powerpoint file that covers the full calculations.

For the simple case, with a front-silvered mirror and no glass to support the vellum, assume the frame has a depth *d* (front-to-back distance), and a dial of width *w* is drawn on the vellum sheet at the front. Assuming that left-right symmetry about the nodus is wanted, then a ray entering through the nodus hole must travel to the mirror and back onto the vellum in a sideways distance *w/2* if it is to just reach the outer edge of the dial face. Hence, in turn, the sideways distance from the nodus to the point where the ray strikes the mirror must be *w/4*. Hence the maximum angle of incidence, *i*, accepted by the dial is given by

$$tan\ i = \frac{w}{4d} \qquad [3]$$

The azimuth of sunset on the longest day, A_{ss}, can be obtained using

$$A_{ss} = cos^{-1}\left(-\frac{sin\ 23.44}{cos\ \varphi}\right) \qquad [4]$$

(adapted from Hosmer, 1914, p.32, equation 13)

Dividing *i* by A_{ss} gives an angular ratio, *ρ*, for how much the dial will need to be declined from south for any given solar azimuth (for the specific case where a linear relationship between the two is desired).

Drawing the dial face involves using [2] to calculate the hour angle of sunset for a series of solar declinations. Multiples of 15° per hour are subtracted from these sunset hour angles to obtain angles corresponding to the hours remaining to sunset. My program uses 10-day intervals for declination, and uses quarter hour intervals for the time to sunset.

Next, the standard equations[7] for solar altitude, *a*, and azimuth, *A*, are used to determine the position of the sun at the required instants. The azimuth must be reduced according to the ratio *ρ* obtained above, and then it is a matter of drawing the corresponding points and connecting lines onto the dial face, bearing in mind that distances must be doubled because of the effect of the mirror.

Fig. 6 shows a top-down view. The origin of the coordinate system is at the nodus, the angle of incidence, *i*, is the ratio-adjusted value just obtained, *d* is the depth of the box.

The x-coordinate used for plotting is given by $2d \cdot tan\ i$ but because *i* corresponds to ρA, this becomes $2d \cdot tan(\rho A)$.

Similarly, the y-coordinate is given by $-2l \cdot tan\ a$, where *l* is given by $\frac{d}{cos\ i}$. Hence, finally, the point's coordinate is:

$$\left(2d\ tan(\rho A), -\frac{2d\ tan\ a}{cos(\rho A)}\right) \qquad [5]$$

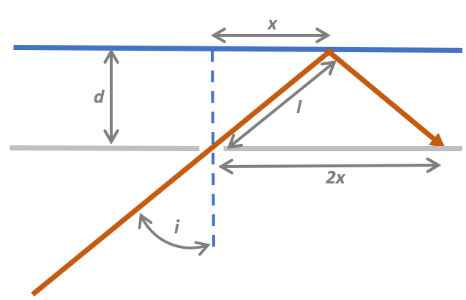

Fig. 6. Calculation of plot points.

[7] $A = tan^{-1}\left(\frac{sin\ h}{sin(\phi\ cos\ h - cos\ \phi\ tan\ \delta)}\right)$; $a = sin^{-1}(sin\ \phi\ sin\ \delta + cos\ \phi\ cos\ \delta\ cos\ h)$ (BSS, n.d.)

Practical considerations

My program, mentioned above, produces a PDF file with declination and hour lines but no labeling. The diagram has to be finished using a drawing program. There is free software called *Inkscape* that is well suited to the task, although it requires the investment of a little time learning how to use it.

The vellum needs to be noticeably translucent and, ideally, should be matched to the type of printer used. I have had tolerable results using inkjet-compatible vellum, *Strathmore Inkjet Translucent Vellum, 30 lb,* in my laser printer - but the surface becomes slightly wrinkled due to heat. My favorite for overall appearance and the best print quality obtained with my laser printer, is *Borden & Riley #90 Sheer Trace Vellum.* When purchasing vellum, I recommend seeking help and advice from a specialist Art Supplies store; I have not had success with the vellums stocked by big chain stores, such as Michaels or Staples in Canada and the USA, as their products are insufficiently translucent and toner adhesion is unreliable.

I like to use a 3 mm glass pane at the front of the box, as well as the polycarbonate sheet that comes with the frames I use. The glass allows me to sandwich the vellum in place, reducing flexing and buckling. Given that there is also a 3 mm mirror in the back, the extra materials mean I usually end up needing to discard the supplied back cover. Working from back to front, the sequence of parts installed is: supplied back cover (maybe), mirror, spacer, glass pane, vellum, polycarbonate. The unit cost is around $15 USD per dial for a 5″ ×7″ example; but note that vellum comes in packs of 25 or 50 sheets so the cost of making a single dial is corresponding higher.

I soon learned that it is impossible to cut the nodus hole in the vellum cleanly using my hand drill. Perhaps a drill press would help, but I do not have access to one. Instead, I started to use a tiny punch. It works fine on lightweight vellum as long as I am careful to line it up perfectly on the printed mark representing the nodus position, and provided I use a scrap piece of hard wood behind the vellum. I make my own 1.5 mm punches by reaming out the tips of dried-up ballpoint pens using a new, hence sharp, ¼″ drill bit; I simply spin the bit using my finger and thumb while pressing it against the soft metal of the open end of the pen tip. My homemade punches are good for about 8 to 10 holes. See Fig.7.

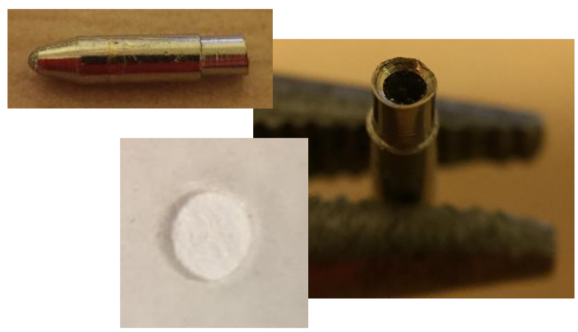

Fig. 7. Homemade 1.5 mm punch and resulting hole.

Acknowledgements

I enjoyed the process of combining three distinct dialing concepts learned from papers and talks by Mac Oglesby, Art Kaufman, and Fred Sawyer. I view it as an excellent example of how the ideas and knowledge of others can give us inspiration for our own projects.

Steve Lelievre steve.lelievre.canada@gmail.com

References

British Sundial Society. (n.d.). *Sundial Equations*. Retrieved December 19, 2018 from http://sundialsoc.org.uk/discussions/glossary-a-z/33/

Hosmer, G.L. (1914). *Textbook on Practical Astronomy*. New York: John Wiley & Sons.

Kaufman, Arthur L. (2015). *Sundial In A Picture Frame*. The Compendium, v. 22, no.1.

Oglesby, Mac. (1997). *A Sundial Showing Hours To Sunset*. The Compendium, v.4, no.1.

Parks, Graham. (2018). *A Sundial for a North Wall*. British Sundial Society Bulletin, 30(iv).

Sawyer, F.W. (2017, August). *Solar Decliners, or Sundials CLARAfied*. Paper presented at the 23rd annual conference of the North American Sundial Society, St. Louis, MO.

The Roman Sundial known as the Ham of Portici

Gianni Ferrari, Modena, Italy

[Until his death in March 2019, Gianni Ferrari was a much-valued contributor to *The Compendium*, writing many enjoyable and illuminating articles over the years. This article is based on material that he presented an Italian gnomonics meeting in 2008. In a later issue of *The Compendium*, we will publish one more article prepared by Gianni: a short paper on the subject of Ottoman dials. I offer my condolences to all Gianni's friends in the sundial community. Steve Lelievre, editor.]

Introduction

While I was doing some research on the famous Roman portable sundial known as the Ham of Portici (Prosciutto di Portici), I came across several sources giving contradictory and unclear information. This led me to make a more detailed study of the instrument. The arguments that I have tried to deal are:

1. The locality of the discovery.
2. The shape of the dial.
3. The working principle.
4. The lengths of the different lines.
5. The year of construction.
6. Drawings of the instrument and their errors.

Fig 0. The Ham of Portici

The object

The sundial was found on June 11, 1755 during the excavation of the Villa of the Papyri near Herculaneum, and is conserved at the National Archaeological Museum of Naples (Inv. 25491). It is a portable dial with a fixed stylus, showing the ancient temporal hours. The time was read by turning the instrument, while suspended, to bring the shadow of the extreme point of the tail (reconstructed in the engraving of Fig. 1) to the vertical line corresponding to the date of observation day.

Sources

A complete bibliography of this instrument is practically impossible because the object, due to its originality, was cited and described in numerous works starting from the last decades of the eighteenth century. For this reason, I limited my search to a selection of texts in Italian, English and French, published from 1780 to the present day. Documentation from the twentieth century is quite poor and extremely limited.

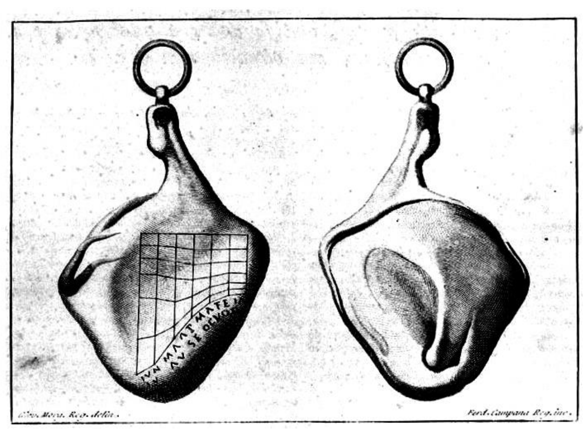

Fig. 1. The engraving that appears in "Le Antichità di Ercolano" (hereafter, AoE).

The most important text is the monumental work *Le antichità di Ercolano e contorni*[8] (AoE), produced by the Academia Ercolanese. The first 8 volumes were published in Naples in the period 1757 - 1792.

These volumes contain many engravings of the paintings, sculptures and objects found in the Herculaneum excavations that started in 1738 by order of King Charles of Borbone. Vols. I, II, III, IV and VII concern the paintings, vols. V and VI the bronzes and vol. VIII the lanterns[9].

The Ham dial, although not a painting, is described in the preface of Vol. III, published in 1762. Its description there, almost an extraneous element in a volume devoted to painting, was included to advertise the discovery, and in response to the authors of the French *Encyclopédie*, who had already indicated that it would appear in the gnomonics chapter of vol. VII of their work[10].

The description by the Neapolitan academics is not only is the earliest, but also, in my opinion, the best found in the texts I examined: is the first and perhaps the only quantitative study of the object[11].

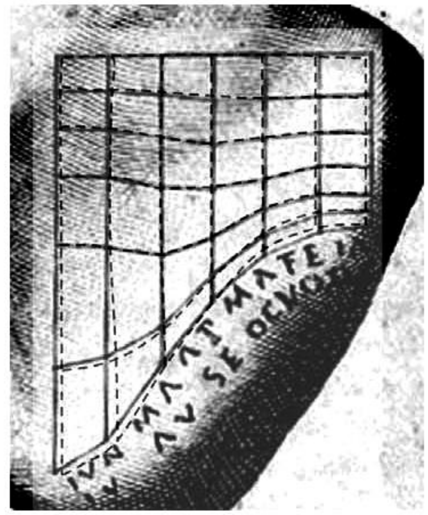

Fig. 2. The hour lines (dashed) measured from a modern photograph superimposed on the engraving.

The report that appears in AoE is accompanied by a precise engraving of the object. Comparing it with a photograph of the object we find only marginal differences in the lines traced, as shown in Fig. 2[12].

The Appendix is a table of the main aspects treated by the different sources consulted, and a few remarks on some of them.

The place of discovery - Ham of Portici or Ham of Ercolano?

As you can see in the Appendix, sources published up to the mid-19th century give the town of Portici as place of discovery; almost all later sources give it as the town of Ercolano.

This lack of unanimity originated, in my opinion, from several causes: the fact that many authors did not read carefully (or at all) the AoE report and they trusted those who had preceded them; the excavations at Ercolano in the mid-nineteenth century and the diffusion of their importance in the world; the simultaneous development of the modern town of Ercolano and the change of the local administrative boundaries occurred over the years.

[8] *The Antiquities of Herculaneum and boundaries, engraved with explanations*.

[9] *Le antichità di Ercolano* is the most important archaeological work of the 18th c. and helped to shape the taste of European culture of the late eighteenth and nineteenth centuries.

[10] The *Encyclopédie* was published between 1750 and 1772. The sundial description is quite imprecise and Neapolitan Academicians, in a long polemic note in AoE, point out the errors committed by the French encyclopedists.

[11] Only in [19] are found some results calculated by J. Drecker for the book *Die Theorie der Sonnenuhren* (1925).

[12] The drawing was made by Giovanni Elia Morghen (1717-1780) while the engraving was by Ferdinando Campana. It must be remembered that King Charles of Borbone, to promote and advertise the relics found in the excavations, set up an engraving school that continued this activity for over a century.

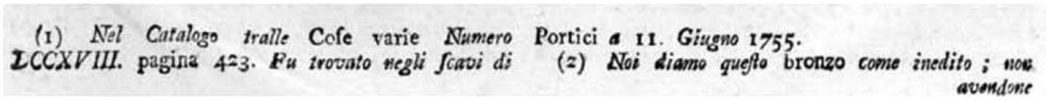
(1) Nel Catalogo tralle Cofe varie Numero LCCXVIII. pagina 423. Fu trovato negli fcavi di
Portici a 11. Giugno 1755.
(2) Noi diamo quefto bronzo come inedito ; non avendone

Fig. 3. Upper: The note in the preface to the 3rd volume, "Ancient paintings of Herculaneum and contours." Lower: The geography of the area.

Any doubt about the location of the find is removed, in the opinion of the writer, by the reading the preface to AoE vol. III where it is stated that the object "was found in the excavations at Portici on 11 June 1755" (Fig. 3). This sentence certainly established the name "Prosciutto di Portici", which translates to "Ham of Portici" in English and "Jambon de Portici" in French.

To try to explain the later reporting it should be remembered that the object was not found in the excavations of the ancient city of Herculaneum, but rather in those of the nearby Villa dei Papiri[13], located almost exactly halfway between the town centers of Portici and Herculaneum.

Materials Used

Although almost all authors agree that the object is silver-plated bronze, the original source (AoE III, p. VIII) states that the object "è inciso nel rame" that is "is engraved in copper" (Fig. 4).

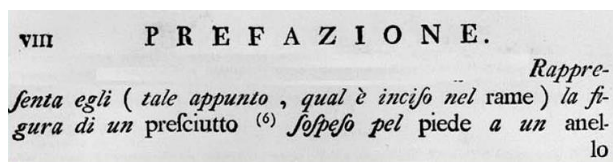
VIII PREFAZIONE.
Rappre-
fenta egli (tale appunto , qual è incifo nel rame) la figura di un prefciutto (6) fofpefo pel piede a un anello

Fig. 4. From "The Herculaneum Paintings" (AoE Vol. III, Preface).

Shape and size

On the shape of the sundial there is nothing more to say: as already stated, the engraving shown in AoE is very precise (Fig. 1).

Nevertheless, probably for reasons already mentioned - careless study of sources and trust in previous works - one finds many different representations, some of which are shown in Fig. 5. It is surprising to see reversed figures, as in [3] and [7]; strange, as in [6]; even absurd, although funny, as in [9] and that of famous engraver Carlo Antonini, from which the former was clearly copied; badly executed as in [13], etc.

I remain surprised by fig. 5 (12), published in 2001 in a very documented article by known scholar De Solla Price. It is almost identical to the one published in 1900 by Mrs. Alfred Gatty [11].

The representation in René Rohr's famous book [13] is also very poor.

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[13] The *Villa dei Papiri* has become universally popular since the mid-nineteenth century because the discovery of more than a thousand rolls of papyrus that were unrolled and read. I remember that Herculaneum, following the eruption of Vesuvius in AD 79, was interred by a rain of ash and lapilli and later by a mudslide.

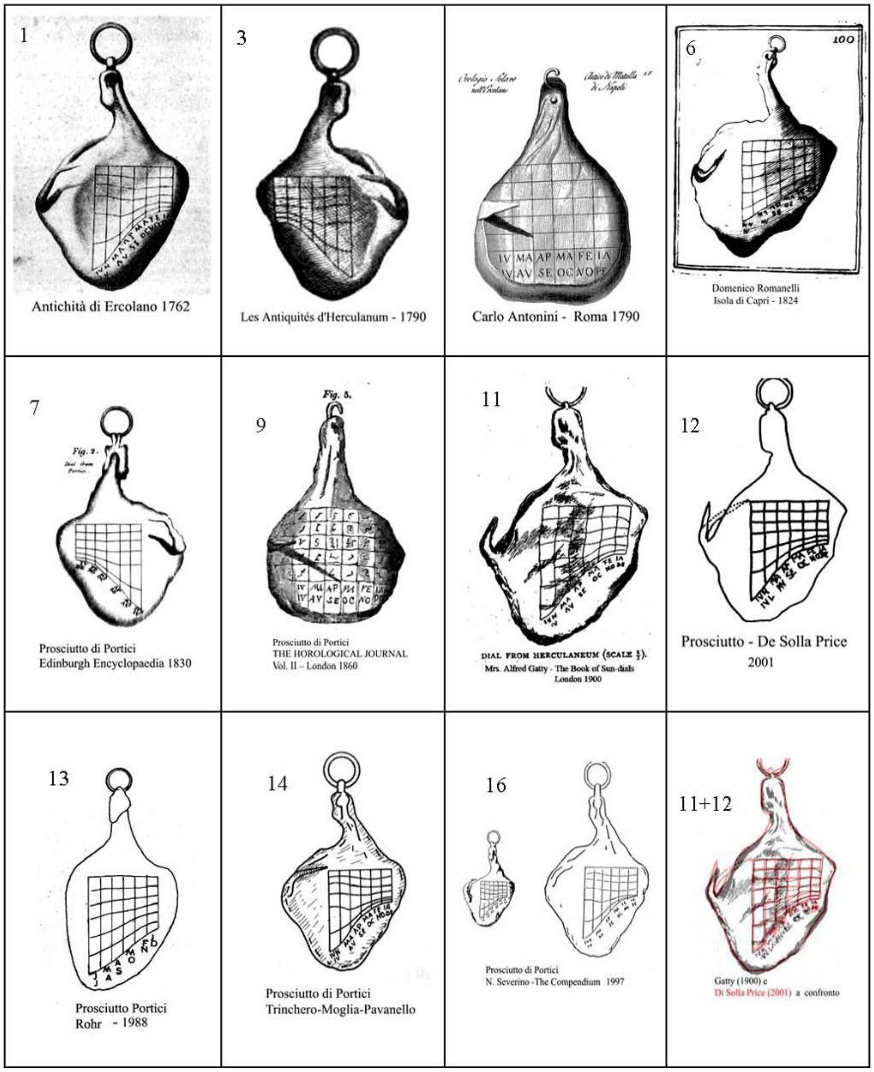

Fig. 5. Different representations of the dial.

The dimensions

Strangely, the original report does not give the actual size of the instrument, nor the dial face. Only the lengths of the vertical date lines are given, expressed in arbitrary units.

I obtained measurements using enlargement of a photograph of the object:

Height:	116 mm	(from the bottom up to the suspension ring)
Width	80 mm	
Thickness	17 mm	

Based on these measurements I obtained, the dimensions of the dial face are:

Width	40.8 mm
Length of date line for Summer Solstice	56.6 mm
Length of date line for Equinoxes	33.5 mm
Length of date line at Winter Solstice	23.1 mm

These measurements are also shown in Fig. 6.

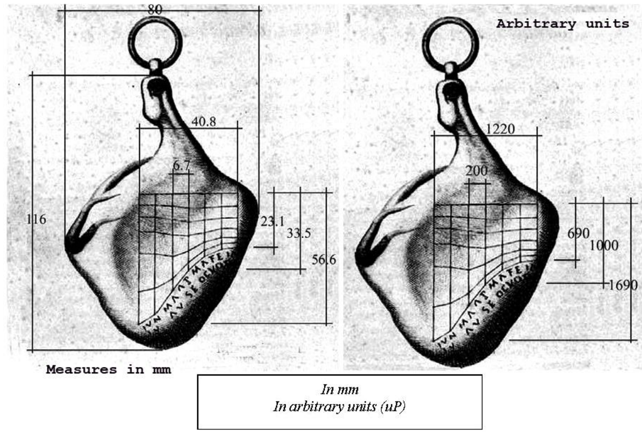

Fig. 6. The sundial's measurements

How the sundial works

The Ham is a portable altitude dial, with fixed gnomon.

The date lines are vertical segments. Each one corresponds to a solar longitude: to the start of a zodiac sign, or day 21 of each month of a modern calendar.

The hour lines show the beginning of Temporary Hours, and resemble those seen in cylindrical sundials such as a Shepherd Sundial.

However, Shepherd Sundials have a movable gnomon so the distance between the daily lines depends only on the diameter of the cylinder, and their lengths only on the gnomon length. In a fixed gnomon dial such as the Ham, the lengths of the date lines depend both on the length of the gnomon and on the distances between them.

As all the altitude dials, those with fixed gnomons must be free to rotate about a vertical axis. For this purpose, they are usually suspended by a little chain or a ring.

The gnomon is typically a short pin perpendicular to the plate and placed at the intersection of the horizon line (top horizontal line) and the line of summer solstice (0° Cancer, Sun Longitude = + 90°, or 21 June, in the Northern Hemisphere)[14]. In the case of the Ham of Portici, the oddly-shaped gnomon was formed like a pig's tail that, projecting from the left side of the thigh, was elongated to bring the tip exactly over the point just mentioned.

Today the tail has disappeared and even when the dial was found there was only a short stump: Neapolitan academics of the eighteenth century rebuilt it using wax, as seen in the engraving of Fig. 1.

To read the time is necessary to rotate the device in order to bring the shadow made by the tip of the gnomon onto the vertical line corresponding to the date of observation (Fig. 7, 8).

This type of sundial is well described in Arabic manuscripts under the name al-Shake Jaradath (The Locust's Leg).

It is not a universal sundial, so the time reading is valid only in the place for which the dial was calculated.

The sundial was explained accurately in almost all the texts examined. It must be noted that the best explanation is that in AoE (1762) and in the monumental work *Histoire de l'astronomie ancienne* and *Histoire de l'astronomie du moyen age* by Jean Baptiste Delambre 1827.

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[14] Theoretically, the gnomon may also be mounted in other positions.

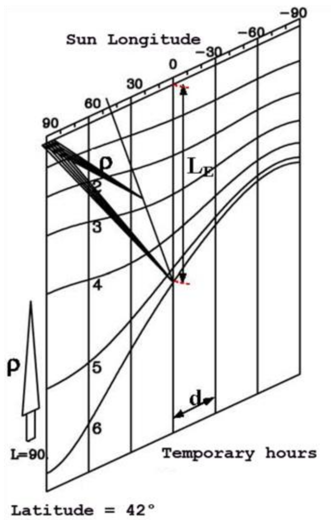


Fig. 7. Altitude sundial with fixed gnomon for latitude 42°N. Shadow at noon on Equinox.

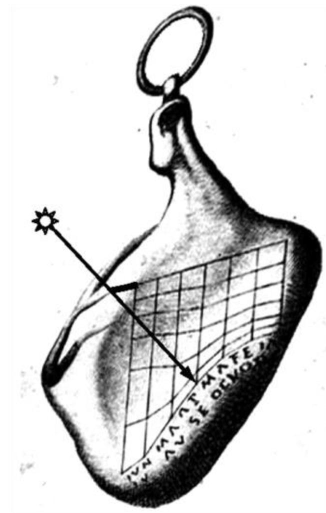


Fig. 8. Simulation with Portici Ham.

The lengths of the lines

In the original report, in AoE, the authors gave measures of numerous lines that appear in the instrument, and also those of some auxiliary lengths used to check the latitude of the place.

The values of all these measures are given in Fig. 6 using an appropriate unit in order to have the length of the equinoctial day line exactly equal to 1000. I will use this unit of measurement, calling it *uP* (Portici Unit)

Using a much-enlarged photograph of the instrument, I measured the lengths of the vertical lines and obtained values almost identical to those of the Neapolitan academics: Fig. 9 shows the AoE measurements with mine in parentheses.

Errors in the measurements

From the reported values (see also Fig. 6) we find that to 1686 *uP* correspond to 56.6 mm and therefore that 1uP corresponds to approximately 0.033 mm.

Assuming measurements with an accuracy of 0.1 to 0.2 mm (in my opinion too large) implies that the data given in AoE can have errors of about 3 to 6 *uP*. The differences between my measurements and those from 1762 fall within these errors.

The calendar scale

As with other Roman portable sundials, described in [12], [17] and [19], the Ham's scale uses abbreviations of the names of the months, instead of the usual zodiacal signs. The abbreviations of the names are written between the two lines corresponding to the solar longitudes of the days starting the signs.

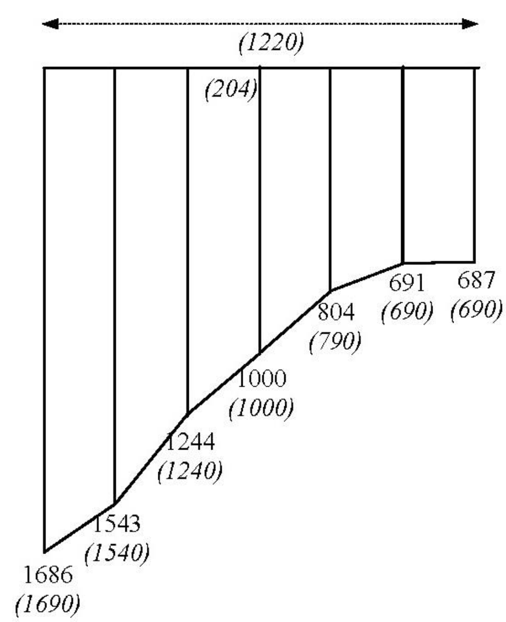


Fig. 9 – The measures in arbitrary units, 1762 and today.

For the Ham of Portici, for example, the abbreviation IUN (June)[15] is placed exactly between the date for line May 21 and that of June 21, and IU (July) between the same lines corresponding now to June 21 and July 21 and so on (Fig. 10).

Fig. 10. The names of the months.

These markings became possible only after the calendar reform by Julius Caesar (and the subsequent improvement made by Augustus). Only with a calendar associated linked to the tropical year, i.e. not lunar or lunisolar, do we have the Sun's celestial coordinates are repeated almost exactly on the same days in following years; with Greek, Egyptian, Hebrew and, later, Arabic calendars there is no agreement between months and solar longitude and therefore it is not possible to mark a scale with the names of the months themselves.

The 1762 results: the first errors

Neapolitan scholars also reported two other lengths (Fig. 11):

- The length *a* of line GA from the end G of the gnomon to the intersection of the horizon line with the equinoctial line, equal to 881.
- The length *b* of line GB from the end of the gnomon to the intersection of the horizon with the Winter Solstice line, equal to 1482.

They did not give the fundamental length, that of line GO from the point G to the dial plane, and they did not mention that this point O must coincide with the point where the horizon line intersects the line of the summer solstice.

Using the two variables, *a* and *b* (Fig. 11) they calculated:

- the value of latitude, $\varphi = \arctan(a / L_E) = \arctan(881/1000) = 41^\circ 22' 48''$
- the value of the declination ε of the sun at the solstice using the formula

$$\varphi + \varepsilon = \arctan(b / L_I) = \arctan(1482/687) = 65^\circ 07' 45.5''$$

Then, on comparing the value of ε with that known in 1762, they found a decrease in ε of 18' 12" and, using the known value of the secular variation of ε (equal to 21' in 2000), they calculated that exactly 1733 years had passed since from the sundial's construction and therefore that it wa constructed in 28.7 CE.

These results are, as we shall see, wrong, but were accepted uncritically by almost all those who later studied this sundial.

The reasoning made by the early scholars is theoretically correct, and the values obtained would have been valid if:

1. The measurements of the dial had no errors.
2. The measures supposed for the lengths of the distances *a* and *b* were accurate.
3. The value of the inclination of the ecliptic ε and its secular variation were correct.

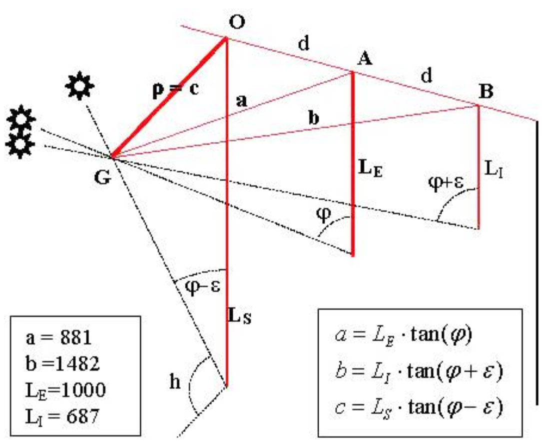


Fig. 11. The elements for the calculation.

[15] The day should really be 25 because with the reform of the calendar of Julius Caesar (46 BC) the vernal equinox was fixed on March 25 (ante diem VII Kalendas Aprilis).

The year of construction

As just mentioned, the year of the sundial construction reported in AoE, 28 CE, was taken as true by most of the sources I studied, as can be seen in the Appendix.

Only Mrs. Gatty [11] and De Solla Price [12] used the correct method and dated the instrument to between 27 BCE and 79 CE. Rohr, in [13], properly suggests the first century CE.

Gatty and De Solla Price argue it as follows: because the Ham shows the month of Augustus (AU in Fig. 10), the sundial must have been built in the period between the year in which the name of the month Sexstilis was changed to Augustus, and the year when Herculaneum was buried by eruption of Mount Vesuvius. The date of the change of the name Sexstilis to the name Augustus is not totally certain. Some texts give this change as 26 or 23 BCE, but the *lex pacuvia de mense augusto*, by which the Senate chose to celebrate the glorious name of the emperor, is certainly from 8 BCE.

In conclusion, therefore, the years for possible construction of the sundial are between 8 BCE and 79 CE.

The errors in the drawing and in the 1762 calculation procedure

The Neapolitan academicians used only some of the measures provided in their report. It seems that they either thought they had completed the examination adequately, or more likely, they found some discrepancies showing that their calculations were not entirely certain, or, finally, in a race with the authors of the French Encyclopédie, they had no time to continue their calculations and experiments.

To continue the examination from the point reached in 1762, I will use the average values I obtained, and taking into account the errors mentioned previously: $\varphi = 41.38°$ and $\varepsilon = 23.7°$

From the formulas (see Fig. 11):

$$\rho = c = L_S \cdot \tan(\varphi - \varepsilon)$$

$$a = L_E \cdot \tan(\varphi)$$

Remembering that LS = 1686 *uP* and LE = 1000 *uP* we can immediately obtain the distances a = 881 *uP* and GO = ρ = 537.4 *uP* (and therefore the perpendicular distance of the nodus = 17.7 mm).

Then we can calculate the distance d = OA and the length OB, the length of the date line or the width of the drawing: OB = 1396.2 *uP*.

The value of this length, measured directly on the dial, is only 1220 *uP*[16]. This difference between the two values for this length is too large to be attributed to small differences between the values of φ and ε used.

In my opinion the difference is due to multiple causes as:

- Incorrect reconstruction of the style with consequent incorrect evaluation of the distance to the plane and then wrong values of the lengths *a* and *b*.
- Error in designing or in making the instrument.
- Confusion between the characteristics of sundials with fixed styles and those of cylindrical sundials with a movable style.

[16] Strangely this fundamental measure is not given in AoE.

The layout of the instrument - New results

To determine if the drawing of the instrument is correct, and errors there are in its operation, I tested two hypotheses.

In each case I ignored some measurements made by the Neapolitan scholars and used only those that can be reproduced today; to maintain consistency with the numerical values reported before, I continued to use the unit of measure *uP*, with which the length of the equinoctial line is equal to 1000.

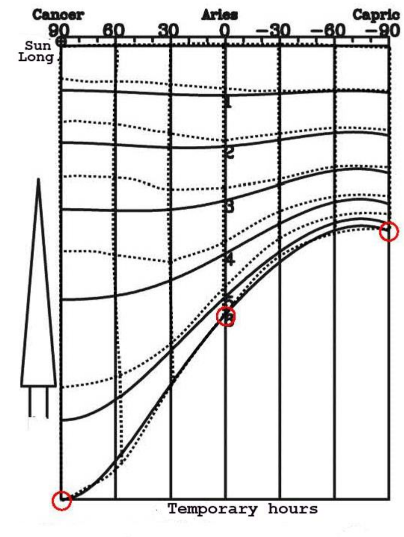


Fig. 12. The true lines (dotted) and those calculated using the 1st hypothesis.

1st Hypothesis

I assumed the lengths that the solstice and equinox daily lines and the width of the dial are correct.

By trial and error, I found that the only values (φ, ε) that give a dial with these measures are $\varphi = 44.5°$, $\varepsilon = 20°$.

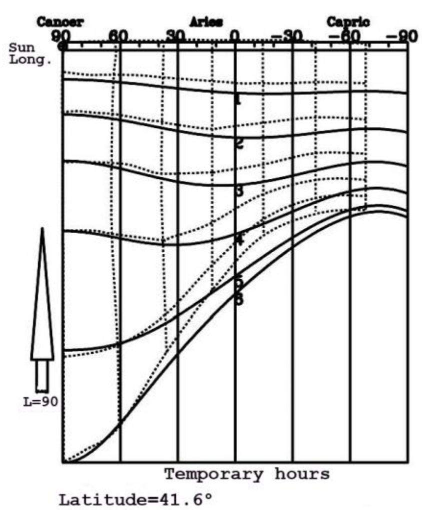
With those, we get OB = 1222 *uP*, $\rho = 770$ *uP*, corresponding to a distance between the tip of the tail, the nodus, and the plane of 25.4 mm (Fig. 11).

Designing the dial with these values we get the drawing in Fig. 12, where the calculated curves are solid lines and those found from a photograph are dotted. The circles indicate the points where the two paths coincide.

We can immediately see that the hour lines differ widely from those engraved on the Ham.

2nd Hypothesis

I assumed that the sundial was calculated with $\varphi = 41.63°$ and $\varepsilon = 24°$, that the lengths of date lines are correct and that the length of the calendar scale is incorrect[17]. The result is shown in Fig. 13.



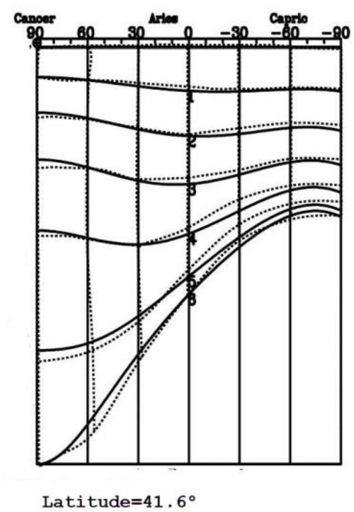


Fig. 13 (left). The ancient path (dotted) and the calculated path.

Fig. 14 (right). The ancient path (dotted) and that "restricted."

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[17] Vitruvius in *De Architectura* - Book IX, Chapter 7 - writes that "The sun, in the days of the equinoxes, that is, when it is in Aries or in Libra, a gnomon of length 9 produces a shadow of length 8, under the inclination of the sky that is in Rome." This, in modern language, means to take the latitude of Rome. For the ecliptic inclination he takes the 15th part of the entire circumference, or 24°.

With these values, the scale of longitude become OB = 1416 *uP* instead of OB = 1220 *uP* as measured on the object. The distance of the point G to the dial plane becomes 537 *uP* or 17.7 mm.

The calculated curves coincide almost exactly with those engraved (dotted) on the line of the summer solstice (left line) and also have similar trends even if deformed.

By restricting, i.e. squeezing, the calculated path (solid line) horizontally until the widths of the two graphs are equal, we get Fig. 14. The hour lines and the lengths of date lines on both dials, old and calculated, practically coincide. Small differences only occur in the winter months when the size of the dial is much reduced and the surface is coarser (Fig. 15).

As a result of this observation several assumptions can be made:

- The designer of the sundial set the distance between the date lines in order to keep the calendar scale in the space available, without any other consideration.

  Maybe he thought that he could reduce the distances between the lines as is possible to do in cylindrical sundial (in which the diameter can be varied at will), confusing the characteristics of the fixed style sundial that he was making with those of cylindrical ones with movable styles.

  Many of those who in last two centuries have studied this little instrument made the same mistake.

- The designer did an excellent job but the engraver (probably the same person), aware of not having a sufficient width after drawing the first line, arbitrarily reduced the distance between the vertical lines to contain the entire drawing in the available space.

- Finally, the engraver began to draw the daily line of the summer solstice (left) leaving too much margin. Indeed, by starting the drawing just about 5 mm (160 *uP*) to the left, the entire dial can be contained in the available surface (Fig. 16).

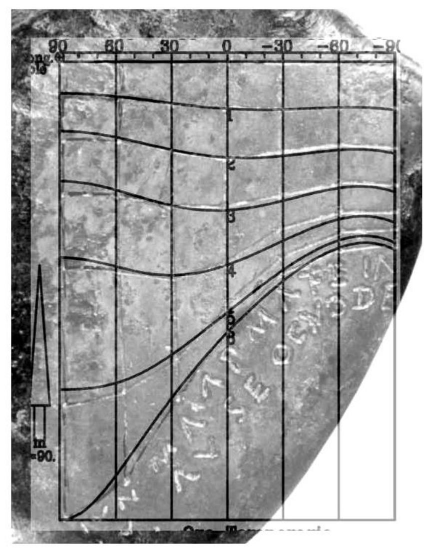

Fig. 15. Photograph of the original lines overlaid by Hypothesis 2 lines.

The errors in reading the hours

Neapolitan scholars asserted that, from experiments made on the day of the vernal equinox, the instrument had marked the hours "exactly" with an error of only 2 or 3 minutes at Italic hour II.

It amazes me that such a result was given, and that it has been accepted, uncritically, by some authors who later studied the instrument.

The equinoctial line is in fact only 33.5 mm long and the widest gap between hour lines, those of the III and IV hours, is only 6.7 mm.

Stating that the error of the time reading is only 2 - 3 minutes is therefore equivalent to claiming to be able to detect a distance of about 0.2 - 0.3 mm.

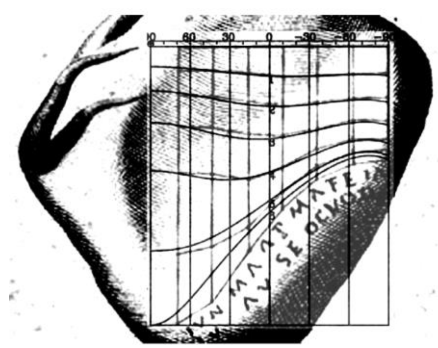

Fig. 16. The ancient drawing and the calculated one shifted to the left.

Aside from other obvious considerations (pig tail reconstructed in wax, a rough and dark surface, width of the engraved lines, etc.), the point G distant is about 18 mm from the plane, and its distance from the shadow is about 31 mm, which implies a shadow of about 0.3 mm in diameter is created by the gnomon tip.

Errors assuming the "restricted" path (Figs. 13 -16)

I assume that the designer, by mistake, has closed up the date lines to achieve a dial face contained in the available area.

To read the hour on a particular day it is necessary to orient the plane of the dial with respect to the sun's position by an angle that differs from what would be used if the width of the calendar scale was wider.

In Fig. 17, OAFE is the plane of the calculated-correctly sundial, with the calendar line OA as 1430 *uP* and OA'F'E is the plane of a dial drawn on the ham with the calendar line OA' as 1220 *uP*.

The same date line (corresponding to a given day in the year) in the two sundials is given by the lines AP and A'P '

The line A'P ' on the engraved calendar represents to the same Sun's longitude as the AP line but actually corresponds to a lower celestial longitude (I'll call it the fictitious longitude).

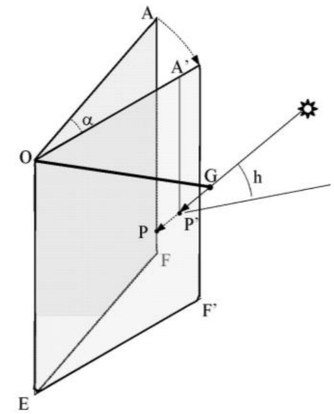

Fig. 17. The error due to the "restricted drawing."

To read the hour at a given time *T* of a day, when the Sun's altitude is *h*, we must bring the shadow of the point G onto the same date in the two sundials; in this way the shadow will be at P' on the incorrect dial and at P on the correct dial.

It is obvious that the times obtained in the two cases are different, because AP and A'P ' are of different lengths.

To show the magnitude of these errors in reading the time due to a "restricted drawing", I have collected in the table below, some examples that assume as correct the lengths of date line of the summer solstice (1690 uP) and that of equinoctial (1000 *uP*)[18]. With these values the length of the gnomon is OG = 549.1 *uP* and scale length of the dates 1430 *uP*.

	Sun's Long.	Temporary Hour	Sun's Decl.	Sun's H. Ang.	Sun's h	Fictitious Long.	Fictitious Decl.	Time shown	Error
Win. Sol.	–90°	End of X	–24°	44.24°	12.4°	–63.9°	–21.42°	10h23m	23m
		End of VIII	–24°	22.12°	20.9°	–63.9°	–21.42°	8h41m	41m
		Noon	–24°	0°	24.0°	–63.9°	–21.42°	7h47m	107m
Equinox	0°	End of X	0°	60°	21.8°	+13.06°	+5.3°	10h21m	21m
		End of VIII	0°	30°	40.0°	+13.06°	+5.3°	8h32m	32m
		Noon	0°	0°	48.0°	+13.06°	+5.3°	7h31m	91m
Sum. Sol.	+90°		+24°			+90°			0 m

As you can see the errors are very large in winter and decreased until they disappear on the summer solstice. They are greater near midday.

[18] All values were obtained assuming the Latitude = 42° and ε = 24°.

A possible method of construction

Almost certainly the instrument was designed using a graphical method, starting from a table of values for the height of the sun at the start of each Temporary Hour on the first day of each zodiacal sign. Almost certainly, these values were obtained using the “analemma method” described by Vitruvius.

A possible method of construction is shown in Fig. 18a, where OB is the upper line (horizon line), divided into 6 parts; OG the gnomon and QF the daily line.

From the triangle OGQ, knowing the distance OQ, we can find the distance GQ = *x*.

Then drawing the line QF, normal to GQ, and using the tabular value of the Sun’s height h_T at the instant required we obtain QP, the segment representing the length of the date line to transfer (by use of a caliper) to provide the point P on the dial face (Fig. 18b).

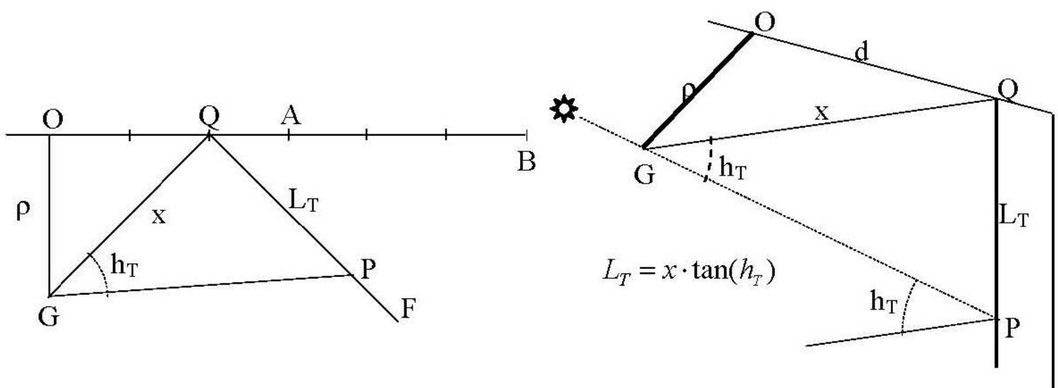

Fig. 18. Left: Dial design with the plane GQP overturned. Right: Axonometric view

Conclusion

We can say that of the Ham of Portici:

- It was found on June 11 1755 in the Villa dei Papiri, near the excavations at Ercolano; the location was at the time of the discovery, within the territory of Portici.
- It was almost certainly constructed in the period between 8 BCE and 79 CE.
- It was probably calculated for a latitude of 41 - 42° and using 24° for the ecliptic inclination – the value given by Vitruvius.
- The construction was carried out with great precision but the engraver or designer made a mistake in positioning the drawing onto the body and was forced to narrow it by changing the functionality, or that the distance between the vertical lines was set in an arbitrary manner, thinking that it was possible as is the case for portable sundials on cylinders.
- The errors in time readings are quite high, ranging from several tens of minutes to hours.
- The instrument probably was a mark of distinction and a jewel, perhaps recalling in its shape the name or the activities of its owner, rather than being a precision instrument giving the correct time.

Appendix: Elements found in different sources

	Author / Publication	Year	Stated Location	Dating	Picture	Stated Material	Desc.	Stated Size (mm)
[1]	Le Pitture antiche di Ercolano (AoE)	1762	Portici	28 CE	Yes	Silver plated copper	Clear and correct	
[2]	Bibliothèque des sciences	1763	Portici	28 CE		Bronze		
[3]	Les Antiquités d'Herculanum	1780	Portici		Reversed		Clear	
[4]	Encyclopédie	1785	Portici near Ercolano	-		Silver plated bronze	Wrong	
[5]	Delambre / Histoire de l'astronomie	1817	Portici	-		-	Clear and correct	
[6]	Isola di Capri	1824	Ercolano	28 CE	Approx.	Silver plated bronze	Good	
[7]	Edinburgh Encyclopaedia	1830	Portici	-	Reversed	-		
[9]	The Horological Journal	1860	Portici Ercolano	-	Invented (from Antonini)	-	Wrong	
[10]	British Archaeological Ass.	1863	-	-		Silver plated bronze		
[11]	Mrs. A. Gatty / The book of sun-dials	1900	Ercolano	28 BCE - 79 CE	Approx. sketch	Silver plated bronze	Outlined	
[12]	De Solla Price / Portable Sundials	1969	Ercolano	28 BCE - 79 CE	Copy from Gatty	Silver plated bronze		116 × 80 × 17
[13]	Rohr. / Meridiane	1988	Portici	1^{st} c. CE	Approx. sketch	-	Outlined	
[14]	Trinchero-M.-P. / L'ombra e il tempo	1988	-	-	Good sketch	-	-	
[15]	N. Severino / Storia della Gnomonica	1993	-	28 CE		-	Copied from [1]	
[16]	N.Severino / The Compendium	1997	Ercolano	28 CE	Sketch + image from [1]	Silver	Copied from [1]	
[17] [18]	M. Arnaldi / Viatoria pensilia	1997	Ercolano	-	Image from [1] & photo	-	Outlined	116 × 80
[19]	K. Schaldach. Römische Sonnenuhren	2001	Ercolano	-	Image from [1]	-	Outlined	116 × 80

Notes on the Table

[1] The work *Le Antichità di Ercolano* never was put on sale and the hundreds of copies of the volumes in folio that were printed were all donated to nobles, eminent personalities and European institutions.

[9] *The Horological Journal*, despite being the most serious watchmaking magazine published in England the nineteenth century, contains numerous significant mistakes:

- The drawing is invented and is a fanciful copy of an engraving made by Carlo Antonini in 1790.
- It states that were several other examples of ham-shaped dials had been found Greece and Rome.
- It asserts that this kind of sundial was not used by Jewish people because of the taboo against pork.
- It states that the object was found in 1754 in Herculaneum and that an identical sundial was found in 1755 in Portici.

[11] Although the description given is one of the most accurate, it states that the object was discovered in 1754 in Herculaneum. The author Mrs. A.Gatty sent a friend, a Miss Lloyd, to copy the object at the Archaeological Museum in Naples but the resulting drawing is not very close to the original. It seems almost certain that Mrs. Gatty did not read the description provided in AoE.

[12] It seems that De Solla Price did not draw on AoE but instead based his description almost certainly on the Gatty book. The drawing that appears in [12] overlaps exactly with that of Miss Lloyd.

Bibliography

[1] Le antichità di Ercolano e contorni, in 8 volumes. Compiled by the Ercolanese Academy. Naples Royal Printing House. Preface to Volume III. 1762.

[2] Bibliothèque des sciences. La Haye, 1763. Vol. I.

[3] Les Antiquités d'Herculanum. Paris 1790. Tome III.

[4] Encyclopédie méthodique: ou par ordre de matiéres... di Jacques–Philibert Rousselot de Surgy, 1785 – “Gnomonique”.

[5] Jean Baptiste Joseph Delambre. Histoire de l'astronomie ancienne. Paris 1817. Tome II; Histoire de l'astronomie du moyen age. Paris, 1819. Tome III.

[6] Domenico Romanelli et al. Isola di Capri. Napoli, 1816 – p. 96.

[7] Edinburgh Encyclopaedia. Edinburgh, 1830. Vol. VII – “Dialling”.

[8] Napoli e i luoghi celebri delle sue vicinanze. Napoli, 1845. Vol II – pp. 484 e seg.

[9] The Horological Journal. London, 1860. Vol. II.

[10] British Archeological Association. London, 1863. Vol. XIX.

[11] Mrs. Alfred Gatty. The Book of Sun–dials. London, 1900 – pp. 185–186.

[12] Derek J. De Solla Price. Portable Sundials in Antiquity, including an Account of a New Example from Aphrodisias. Centaurus. 1969 – v.14, no.1, pp. 242–266.

[13] René Rhor. Meridiane (It. translation). Edizioni Ulisse, 1988 – pp.19–20.

[14] Trinchero, Moglia and Pavanello. L’ombra e il tempo, 1988. p. 352.

[15] Nicola Severino. Storia della Gnomonica, 1993 – pp. 69–74.

[16] Nicola Severino. The Portici Ham. In *The Compendium* – v.4, no.2, 1997 – pp. 24 -. Republished in *La Busca de Paper* - n.53, 2005.

[17] M. Arnaldi. Viatoria pensilia, Acts of the VIII Italian Gnomonic Seminar, October 1997, pp. 44-45.

[18] Mario Arnaldi, and Manuel M. Valdés. Su alcuni orologi solari da viaggio romani. In *Astronomia* [magazine of Italian Amateur Astronomers]. Padova, 1999 – no. 2, pp. 2–9.

[19] K. Schaldach. Römische Sonnenuhren. Verlag Harri Deutsch. Frankfurt, 2001 – pp. 42, 43.

The Tower of the Winds, Part 2

Paolo Albèri Auber (Trieste, Italy)

Abstract

In Part 1 of this study, I described the Tower of the Winds and its history, and summarized the most important earlier studies.

In a paper published by the Società di Minerva, I calculated the positions that the Tower's original gnomons would have occupied [ALBERI 2006]; here I summarize that analysis for the use of dialists, showing:

1. The intended latitude, length and position of the gnomons. [Note, if you are not familiar with the gnomon configurations used in ancient sundials, you may find it useful to read the appendix "*The gnomons of antique sundials"* before proceeding. Ed.].
2. The calculations presented here are restricted to the S, N, SE, E, and NE dials, under the assumption that the SW, W, and NW designs are symmetrically identical to the SE, E, and NE dials.

Delambre (1817), Palaskas (1845), Drecker (1925), and Hüttig (1998) calculated the required gnomon lengths based on survey drawing by Stuart & Revett (1762), sometimes using a different value for the ecliptic angle; their results are presented in Fig. 1. Fig. 2 shows the calculated latitude for each sundial and the value of the ecliptic angle used for this purpose. This paper also provides gnomon positions on the walls, assuming a perpendicular rod-type gnomon.

Fig. 3 is a schematic plan of the octagonal Tower showing, for the eastern sundials:

1. The lengths of the perpendicular gnomons.
2. The intended latitude.
3. The position of the foot of the gnomon below the cornice, with respect to the right (or left) vertical border of the wall. Note, an inclined gnomon could be implanted above the cornice, in the way Andronikos did, provided the nodus position remains unchanged.

	Delambre		Palaskas		Drecker		Huettig		Alberi	
	gnomone	eclittica	gnomone	eclittica	gnomone	eclittica	gnomone	eclittica	gnomone	ecl.
	mm	gradi	mm	gradi	mm	gradi	mm	gradi	mm	gr.
SUD-Notos	267	23,85	272	23,7	275	23,85	271	23,7	264	24
SUD-EST-Euros	648	23,85	642	23,7	642	23,9	641	23,7	649	24
EST-Apeliotis	488	23,85	488	23,7	487	23,9	494	24	475	24
NORDEST-Kaikias	167	23,85	226	23,7			192	23,7	180	24
NORD-Boreas	267	23,85	127	23,7			271	23,7	295	24

Fig. 1. The lengths of the gnomons (ortho-styles) as calculated by various scholars.

latitudine													
corrente													
ATENE	Delambre		Palaskas		Drecker		Gibbs		Huettig		Alberi	
37,976	latitudine	eclitt.	latitudine	eclitt.	latitudine	eclittica	latitudine		latitudine	eclitt.	latitud.	ecl.
	gradi	gradi	gradi	gradi	gradi	gradi	gradi		gradi	gradi	gradi	gr.
SUD	37,5	23,85	?		37,66	23,85	37,33	?	37,97	23,7	37,74	24
SUD-EST	37,5	23,85	37,83	23,7	37,83	23,9	38,18	?	37,97	23,7	38,01	24
EST	37,5	23,85	37,93	23,7	38,85	23,9	38,8	?	38,66	24	38,4	24
NORD-ES	37,5	23,85	?						37,97	23,7	39,3	24
NORD	37,5	23,85	?						37,97	23,7	36	24

Fig. 2. The intended latitude of the dials and the corresponding ecliptic angle used for the calculation.

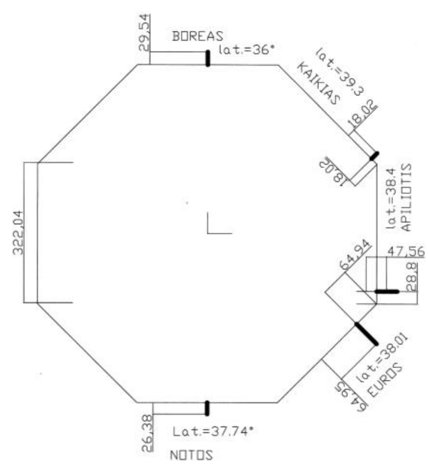

Fig. 3. A schematic plan of the octagon, showing attributes calculated for the dials on some of the faces.

The gnomonic data of the Southern Sundial (NOTOS).

Fig. 4 is a photograph of the southern dial.

Fig. 5 is the survey drawing by Stuart & Revett.

In Fig. 6, Stuart & Revett's sundial (continuous lines) are subjected to a graphical comparison with calculated (dotted) lines. Andronikos' dial seems to have been laid out quite accurately.

I clarified some contradictions in Stuart & Revett's lines by actual measurements (Fig. 7), made by me with the help of Dr. Angelo Zarkadas of the Hellenic Ministry of Culture (1st Ephorate, Athens).

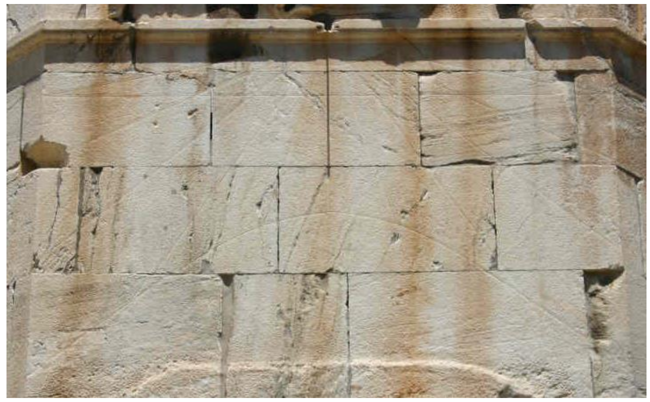

Fig.4. 2005 photograph of the Southern Sundial (NOTOS).

Fig. 8 shows the axonometry of the nodus, or projecting point, for the southern sundial. Regardless of its length, the projecting point has to be placed on the lower line of the cornice, i.e. the horizon of the sundial.

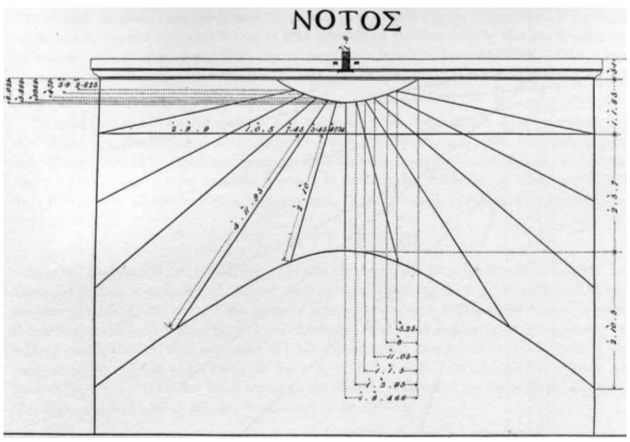

Fig. 5. The accurate, detailed drawing of the southern dial made by Stuart & Revett (1751-53).

Fig. 7. Checking the dimensions given on the 18th century drawings.

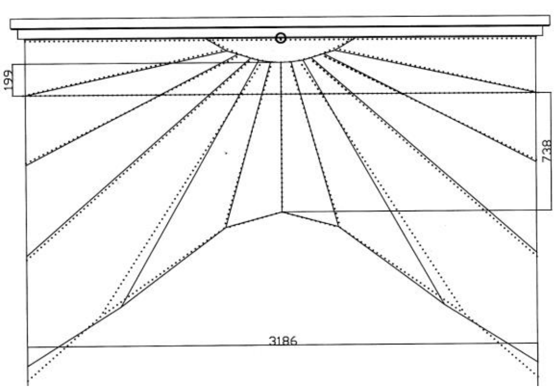

Fig. 6. The Stuart & Revett drawing (continuous lines) compared with calculated lines (dotted lines) of the southern dial.

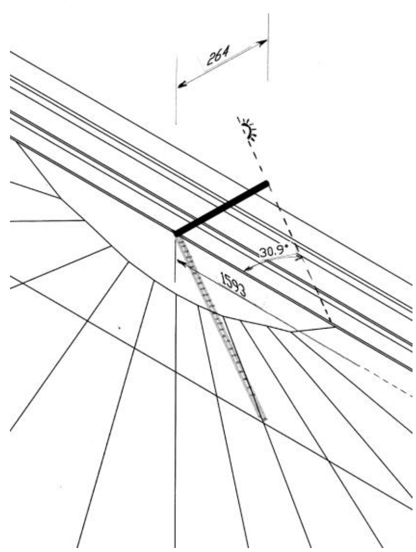

Fig. 8. The projecting point for the southern sundial as calculated by me (axonometry).

The gnomonic data of the South-Eastern Sundial (EUROS).

Fig. 9 is a photograph of the South-Eastern sundial. Fig. 10 is the survey drawing by Stuart & Revett. In Fig. 11 the survey (continuous lines) is compared with the calculated (dotted) lines. Andronikos' lines seem to be carved quite accurately.

Fig. 12 shows the axonometry of the correctly-calculated projecting point for the South-Eastern sundial. Once again, the nodus has to line in the plane of the lower edge of the cornice, i.e. the horizon of the sundial.

It is evident from Fig. 9 that the replacement gnomon (Fig. 9) has been sited incorrectly - too far to the right side of the wall.

Fig. 9. 2005 photograph of the southeastern sundial (EUROS).

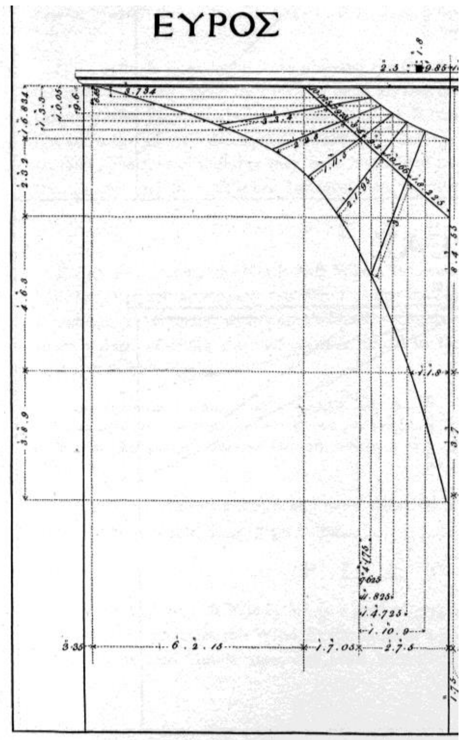

Fig. 10. The accurate, detailed drawing by Stuart & Revett (1751-53) of the southeastern sundial.

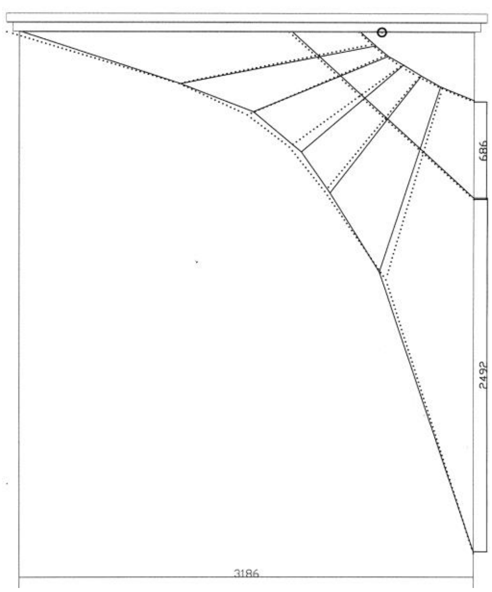

Fig. 11. Stuart & Revett's survey (continuous lines) compared to calculated lines (dotted). SE dial.

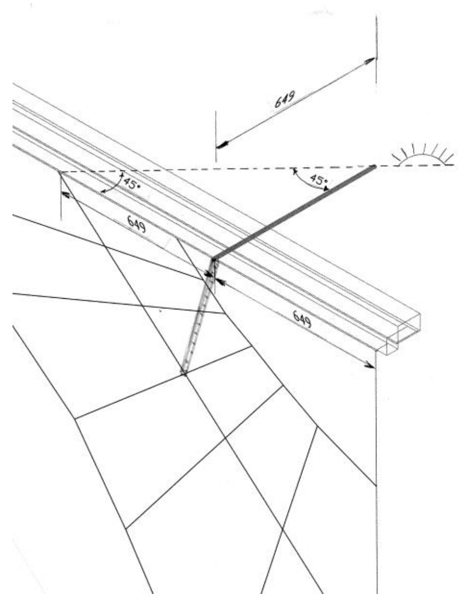

Fig. 12. Axonometry of the SE dial.

The gnomonic data of the Eastern Sundial (APELIOTIS)

Fig. 13 shows the eastern dial, Fig. 14 shows the surveyed tracing of Stuart & Revett, and Fig. 15 shows Stuart & Revett's sketch (continuous lines) and calculated (dotted) lines. Andronikos' lines are again positioned accurately.

Fig. 16 provides the axonometry of the correctly-calculated nodus position for the Eastern Sundial, showing that the perpendicular replacement gnomon should have been placed at the lower side of the bottom ledge of the cornice, i.e. the horizon of the sundial, and not in the slightly higher position seen in Fig. 13.

Fig. 13. A 2005 photograph of the eastern dial (APELIOTIS).

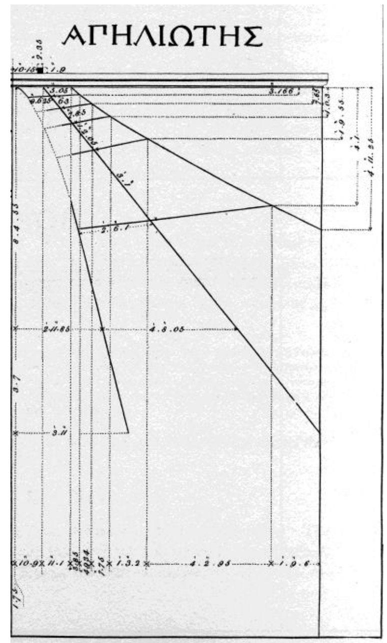

Fig. 14. The accurate and detailed drawing by Stuart & Revett (1751-53) of the eastern dial.

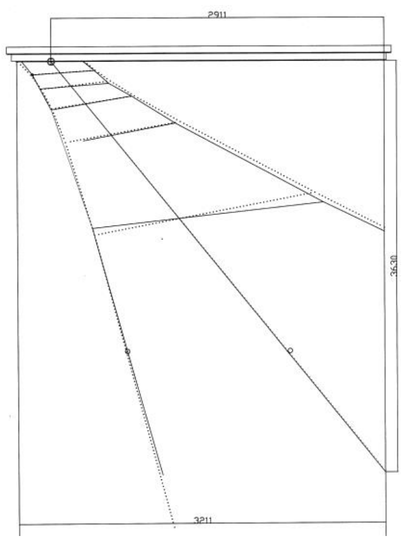

Fig. 15. The drawings by Stuart & Revett (continuous lines) and calculated lines (dotted) of the Eastern dial.

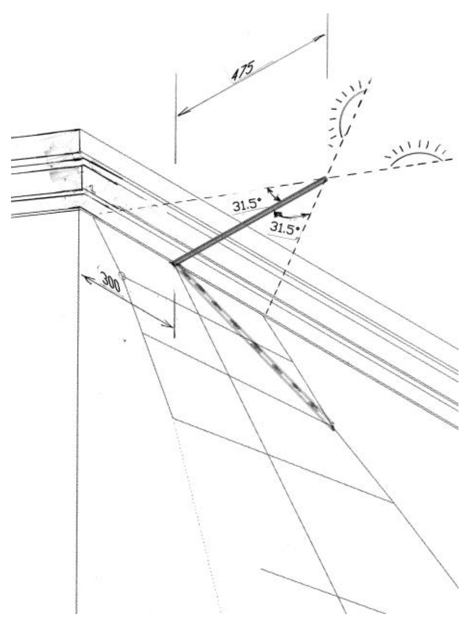

Fig. 16. The axonometry of the projecting point for the Eastern dial.

The gnomonic data of the North-Eastern sundial (KAIKIAS)

Fig. 17 shows the north-eastern sundial, Fig. 18 the survey by Stuart & Revett, and Fig. 19 the Stuart & Revett diagram (continuous lines) compared with calculated (dotted) lines – showing yet again that Andronikos' lines seem to be well laid out.

Fig. 20 is the axonometry of the correctly-calculated nodus of the North-Eastern sundial. The projecting point (nodus) should be placed at the lower edge of the cornice, i.e. on the horizon of the sundial.

Fig. 17. A 2005 photograph of the North-Eastern sundial (KAIKIAS).

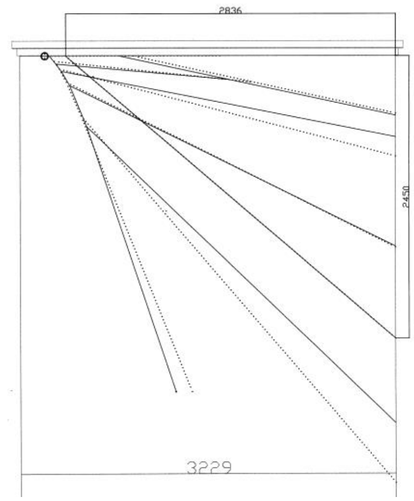

Fig. 19. The drawings of Stuart & Revett (continuous lines) subjected to a comparison with the actual calculations (pointed lines) of the NE sundial: Andronikos' sundial seems to be calculated and outlined rather accurately.

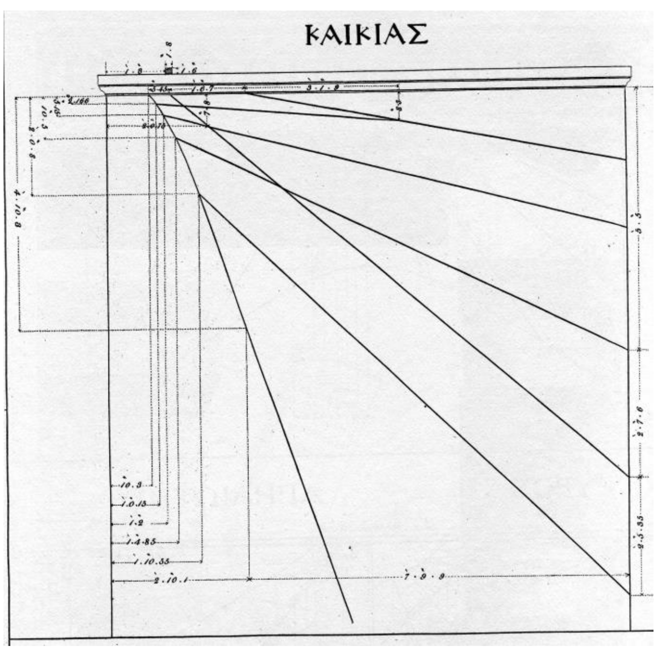

Fig. 18. The accurate and detailed drawing of Stuart & Revett (1751-53) of the North-Eastern sundial.

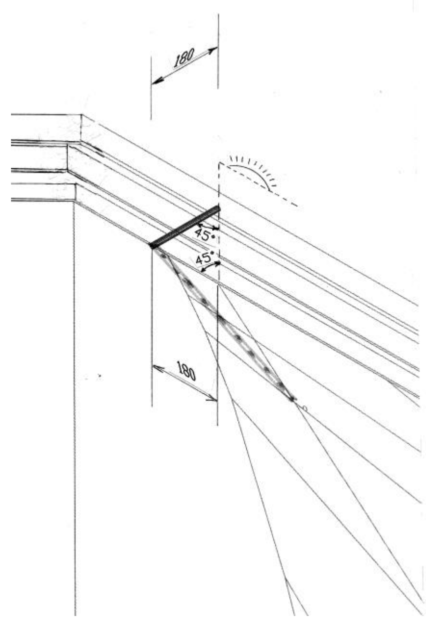

Fig. 20. The axonometry of the projecting point for the North-Eastern sundial as calculated by me.

The gnomonic data of the Northern sundial (BOREAS)

Fig. 21. A 2005 photograph of the Northern Sundial (BOREAS.)

Fig. 21 is a photograph of the Northern sundial. Fig. 22 is the survey drawing from Stuart & Revett. In Fig. 23 the Stuart & Revett drawing (continuous lines) are subjected to a graphical comparison with calculated (dotted) lines. Here, with the Northern dial, we encounter a significant discrepancy - some of Andronikos' lines seem to be laid out incorrectly. The dashed lines represent impossible lines from Andronikos' Northern sundial; the summer solstice date line is correctly traced, but the 1st and 11th hour lines are not.

At the latitude of interest, there is no sun and consequently no shadow from the north direction (midnight) so these incorrect lines, set out by Andronikos, indicate that the sundials were not merely traced "par l'observation", as supposed by Delambre.

In contrast, because such errors are plausible only if calculating by mathematical methods, we can consider them as proof that all the Tower's sundials were in fact traced "by calculation" - using the well-known sophisticated mathematical-geometrical method: the Analemma[19]. The Analemma was described by Vitruvius (De Architectura – [IX, 7, 2-7], 2nd part of the 1st century BCE) and, later, by Ptolemy (De Analemmate, 1st part of the 2nd Century CE).

In Fig. 24 the axonometry of the correctly calculated projecting point for the Northern sundial. Independently from the length in any case the projecting point was necessarily to be placed on the lower line of the cornice, i.e. the horizon of the sundial.

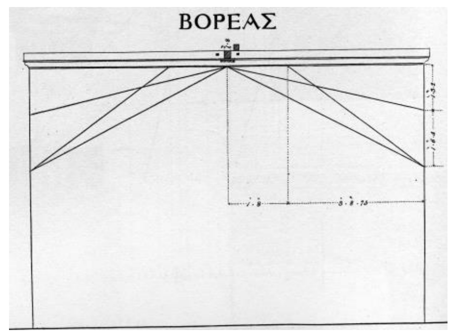

Fig. 22. The Stuart & Revett drawing (1751-53) of the Northern Sundial; some lines cannot be traced by following the shadow of a central style: none of the lines which originate in the upper central point match real hour lines.

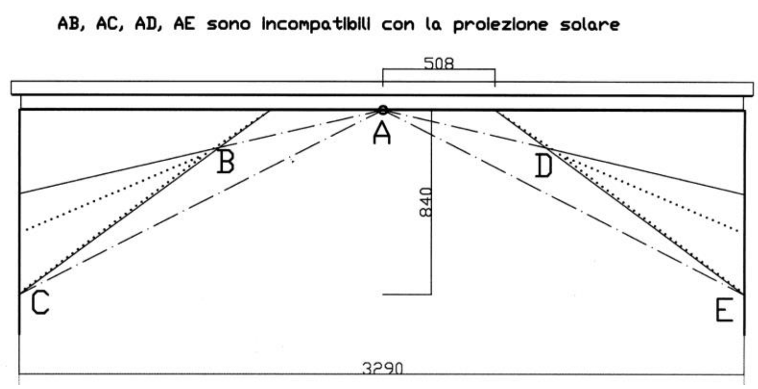

Fig. 23. The drawings by Stuart & Revett (continuous lines) subjected to a comparison with the actual calculations (pointed lines) of the Northern sundial. The dashed lines trace the impossible lines of Andronikos' Northern sundial. The summer solstice date line is correctly traced but the 1st and 11th hour lines are not.

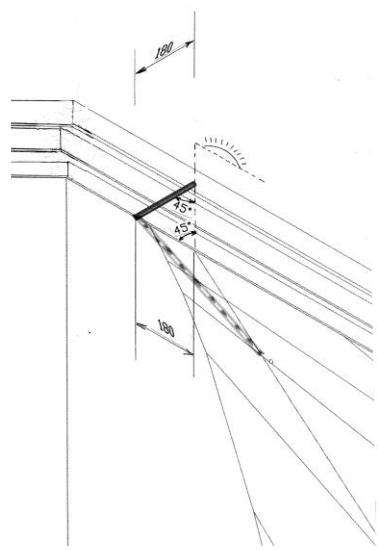

Fig. 24. The axonometry of the projecting point for the Northern Sundial.

[19] [The Analemma of Vitruvius is a graphical construction method, not to be confused with the modern "figure 8" representation of the Equation of Time. Ed.]

Conclusion

The sundials of Andronikos Cyrrestes (ca. 100 BC) have been very accurately calculated and traced on the eight walls of the Tower of the Winds in Athens. The exception of the northern sundial, where some lines are not compatible with the Nature, is proof that the sundials were calculated by means of a mathematical instrument, the Analemma, and not “par l’observation” (Delambre). The 3D arrangements shown here using axonometry represent the correct projecting points for the sundials: they could be used, in case of interest, by the Greek Authorities in restoring Andronikos’ – (Palaskas’ - XIX cent.) gnomons being the current time gnomons wrongly placed. In the previous issue of “The Compendium” I reported the opinion (the hours read on the sundials are inappropriate) of two scholars (Bromley – Wright) and a table of hours read by me which demonstrates the same evidence.

Appendix - the gnomons of antique sundials

It is well known that the hour lines of a conventional modern sundial converge at a point; this point is the toe of a polar style. In contrast, antique, or unequal, hour lines do not converge at a single point. Furthermore, they are not true straight lines, mathematically speaking; this was shown by C. Clavius in 1593. We should not be surprised that the hour lines were always traced as straight lines in planar antique sundials. When projecting a dial with antique hours it would be obvious that the hour lines are not straight only at a very high latitude, 60° or more; at lower latitudes the deviation from a true straight line is negligible. This complex question has been discussed by Drecker (1925) and Aulenbacher (DGC Mitteilungen, Summer 2016).

That said, it is clear that in the antique sundials only the shadow of the extremity of the metal gnomon functions as a projecting point for the solar rays; we correctly call it a "nodus". Once you understand that only the extremity of the metallic rod gnomon is used for indicating the hour (and the season), the actual form of the gnomon could then be:

1. A simple hole in the roof, as in the dials that Gibbs calls (roofed) spherical-variant sundials.

2. A horizontal rod as seen in almost all the spherical and conical sundials

3. A rod perpendicular to the surface of a planar sundial. This form, obvious to modern gnomonists, is very rarely seen, or perhaps unknown, in antique planar sundials:

- For the Pelecinum (two coupled planar vertical sundials, oriented SE and SW), rather common in the later Roman Empire, the gnomon was a horizontal south oriented rod,
- In the horizontal sundial of the Circus in Aquileia (other horizontal sundials are extremely rare) the gnomon is formed like an inverted letter L so that the slot for fixing it in place is far enough from the summer date line to avoid interference.
- In our case, the Tower of the Winds in Athens, the metallic rods were originally fixed over the cornice, perhaps with a similar purpose to the case of the Aquileia Circus. They were oriented downward in the perpendicular plane in the case of the S, N, E, and W dials; the others were also oriented in a lateral direction (SE, SW, NE, NW sundials). The calculation of the "down" and "lateral" position of the nodus (projecting points in SE, SW, NE, NW sundials) is clearly and indubitable confirmed from the drawings by Capt. Palaskas. See [ALBERI 2006] Fig. 9.

Of course, I here propose theoretical gnomons explicated by means of horizontal or perpendicular rods (Fig. 3): they only help to show where the nodus, the point of projection, has to be positioned.

In any restoration, the rod should be fixed above the cornice, where possible mounting holes in the marble already appear, sealed by means of lead. Palaskas' gnomons had a very sharp triangular (or conical or pyramidal) form, the same way as the horizontal gnomons on, practically, all spherical sundials had a very tight triangular form (only the form, not the orientation).

Bibliography

[Alberi 2006] Paolo Alberi, "Gli Orologi Solari della Torre dei Venti di Atene e a Tinos del greco Andronico Cyrretse" Archeografo Triestino – Società di Minerva Trieste 1810 – Serie IV – 2006 – Volume LXVI (CXIV della Raccolta).

[DELAMBRE 1817-1965] J. B. Delambre "Histoire de l'Astronomie Ancienne" Parigi 1817, London, 1965.

[PALASKAS 1846] M. L. Palaskas "Memoire presente a la Societe Archeologique d'Athens, le 15 de Novembre 1845" in "Resume des Actes (Sinopsis ton Praktikon) de la Societe Archeologique d'Athens" Atene 1846.

[DRECKER 1925] Joseph Drecker "Theorie der Sonnenuhren" in "Die Geschichte der Zeitmessung und der Uhren" a cura di Ernst Basserman-Jordan, Berlin-Leipzig, 1925.

[GIBBS 1976] Sharon Gibbs "Greek and Roman Sundials" New Haven – London, 1976.

[HUETTIG 1998] Manfred Hüttig "Analysis of the Sundials on the Tower of the Winds, Athens – Possible Parameters used in construction" in Bulletin of the British Sundial Society, No 98/3 Oct. 1998.

[STUART REVETT 1762] James Stuart – Nicholas Revett "The Antiquities of Athens", London 1762.

The Tove's Nest….

Response to an inquiry about the origin of the term 'Temporal Hours' – Mario Arnaldi – marnaldi@libero.it

> *The seasonal hours take the name "temporal" from the Latin "tempora" (plural) that are the seasons (the four "tempora"). Hope I made clear the mystery.*

Video profile of an Hourglass maker – via Patrick Vyvyan – patrickvyvyan@gmail.com

https://www.bbc.com/reel/playlist/the-truth-about-time?vpid=p074qxxh

Digital Bonus

Subscribers to the Digital Edition receive 2 Microsoft Powerpoint files with this issue, both containing slide packs for presentations given at the 2018 NASS conference:

Slides showing some of the fascinating astronomical features built into the home of Rubén Hernández Herrera, in Corregidora, Mexico; several video clips are also included.

Slides for a presentation by Steve Lelievre about his mirror-box-solar decliner dials, as also described in his article at page 14 of this issue. NB: The slides cover the calculations relating to ray paths with more detail than the article provides.

Sundial at a residence in the Gavilan Hills, Costa Rica

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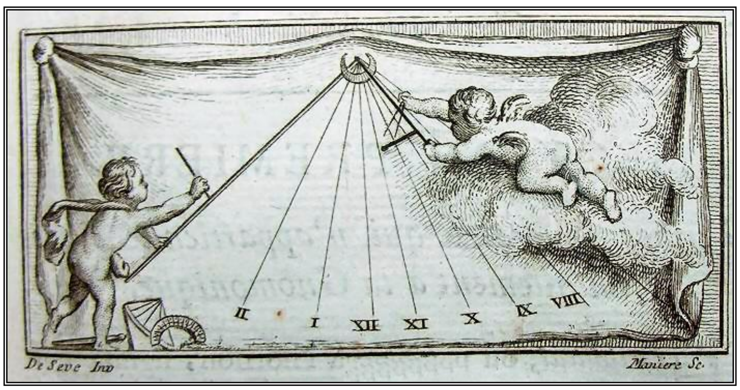
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